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Analysis of Meteorological Conditions During the 1977 Anclote Keys Plume Study

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Analysis of Meteorological Conditions During the 1977 Anclote Keys Plume Study

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The forecasting center, radiosonde, pilot balloon, and tethersonde systems are also described, and the data acquisition schedules are included. Raw pilot balloon and tethersonde observations and the derived wind fields are not included, but are available from the authors.

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Meteorological conditions are described and analyzed for nine experimental observation periods of the Anclote Keys Plume Study, which was conducted near Tampa, Florida during February 1977. The primary objective of the Plume Study was to investigate both the short and long range transport of power plant plumes and the formation rate of sulfate in a marine environment.

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SECTION 1

INTRODUCTION

In the recent airborne studies of power plant plumes, simultaneous air-chemical and meteorological documentation has proven to be essential not only for planning the operational mode but for the post-flight synthesis of the plume-ambient air interaction. Environmental Quality Research, Inc. has cooperated with Environmental Protection Agency scientists over the past several years to produce accurate and timely data for the resolution of important air pollution problems.

The purpose of the Anclote Keys Plume Study was:

1. Measure the sulfate formation rate.
2. Measure the mass flow of pollutants as a function of the distance from the source.
3. Investigate the long range transport of power plant plumes.
4. Determine the influence of a marine environment on a power plant plume.

The procedure used was to combine the aircraft monitoring of the pollutant concentrations in the plume with ground-based monitoring of the meteorological parameters in the near plume ambient atmosphere.

EQR has combined its radiosonde, pibal balloon and meteorological forecasting expertise with the newly acquired TETHERSONDE system. This TETHERSONDE system automates the acquisition and reduction of measurements of vertical profiles of temperature, humidity, winds, and many other derived quantities. EQR's participation in the Anclote Keys Plume Study involved the following tasks:

1. Set up prior to the experiment a command center reasonably close to the Anclote Power Plant from which radio communications could be maintained with the sampling aircraft and with the meteorological ground crews,

2. Equip the command center with a meteorological communications network sufficient to allow the EQR supplied Forecaster to make short and long term operational forecasts,
3. Hire, train, and deploy two (2) single pilot balloon crews, one (1) double pilot balloon crew, and one (1) TETHERSONDE crewman and procure and transport all meteorological equipment for crews to deploy during each flight in coordination with EPA supervisory personnel,
4. Set up a radiosonde station with personnel and maintain a release and data reduction schedule at the EQR fixed site to produce on-line documentation of atmospheric conditions,
5. Receive and reduce real time pibal data at the radio command center for operational use during each flight,
6. Quality control all pibal, radiosonde, and TETHERSONDE data, and
7. Produce meteorological data summaries describing the power plant plume's ambient conditions during the experimental period Feb 7-18, 1977.

The data report summarizes the results of the two week operation, presents the meteorological data taken, and displays a synopsis of the meteorological conditions under which the experiment took place.

SECTION 2

CONCLUSIONS

During the two week Anclote Keys Plume Study meteorological conditions were ideal for various types of plume sampling. The occurance of extreme stability conditions at times permitted the tracking of a coherent plume well over a hundred kilometers from the source. Plume characterizations were accomplished under stable and unstable conditions both onshore and offshore.

EQR successfully prepared and operated the command center so that the operation began on Feb 7 as scheduled. All meteorological communications were operable as prespecified. Air to ground and ground to ground radio communications, were also headquartered at this fixed site.

Radiosondes were launched continuously from the EQR fixed site. Supplementary data from the Ruskin, Florida National Weather Service radiosonde station were acquired.

Single pilot balloon crews (2) were deployed downwind of the power plant whenever possible to support all plume sampling flights. The double pibal crew occupied two coastal sites, one each week, also in conjunction with flight operations. Data gathering efforts of this crew during the first week were somewhat diminished because of the operational difficulties encountered while manning a site on the uninhabited Anclote Keys just offshore from the power plant.

TETHERSONDE operations, to accomplish continuous low level sampling of the atmosphere, were set up onboard the research vessel Tursiops which patrolled the Gulf waters west of the Anclote plant. Efforts were made to anticipate the downwind position of the plume and to document the ambient conditions. The lack of mobility of the vessel as well as the high degree of diurnal variability of the coastal winds made efforts to get directly

under the plume unsuccessful. High winds and seas limited the utility of the TETHERSONDE system. An electronic deficiency, now corrected, prevented data collection when wind speeds exceeded 10 meters per second.

The data from all the meteorological communications systems as well as the raw data collected during the experiment were returned to EQR headquarters and were quality controlled. Data were visually inspected as well as plotted to ensure vertical and time continuity. Tables, commensurate with EPA needs for pollutant mass flux calculations, have been prepared. A climatic summary has been included in the data report synthesizing all available data. All project goals, as described in Section 1, have been achieved.

SECTION 3

RECOMMENDATIONS

Despite the successful coordination between EQR and EPA operations several facets of the joint effort should be improved upon during future power plant studies.

A complete radio communication system connecting all important personnel to the central location is imperative for coordinated plume sampling experiment. Several additional ground to ground FM radios were needed to tie in all meteorological crewmen to the fixed site. Two-channel ground to ground FM radios should be utilized by the double pibal crews, one channel for base communications, the other for the site to site communication needed to produce simultaneous readings. Battery operated walkie-talkies proved inadequate. The drain of continuous use and the awkwardness of using the unit during operations necessitates this change.

Two personnel who are not in any way involved in data gathering are needed to manage data gathering crews, reduce incoming data, produce on-line data analyses, and to produce operational forecasts. Many of the above tasks were critically overlapped and could not be accomplished using one person.

Computer-based meteorological data communications facilities should supplant conventional Weather Services longline data at the field operations center. Special programs and data packages can be generated at EQR and communicated to the field on a scheduled basis or on request. A medium speed printer and graphics display terminal in the field will allow for maximum use of all meteorological data.

It is also recommended that a new, expendable (one-way) radiosonde package be used which is compatible with the TETHERSONDE signal receiving station, microprocessor, and HP-97 link up. This combination would result in fully-automated, real-time acquisition and printout of high-resolution temperature

and moisture profiles as a function of height to altitudes in excess of 6 km (20,000 ft). Balloon tracking by theodolite and a manual entry of elevations and azimuths into the HP-97 must still be done to derive on-line winds.

It is recommended that in subsequent TETHERSONDE field operations, the Channel A (time-multiplexed) data stream be recorded via interface on an audio cassette tape recorder. In this manner, the partially-processed data record may be later replayed into the HP-97 micro-computer for quality control and final processing to generate hard copy records. This procedure results in a tape data record, and for some applications can also eliminate the need for field use of the HP-97.

Double pibal operations were hindered by the lack of precision timing and reading that is required for accurate results. It is suggested that a second ground to ground FM channel be used in conjunction with tape recorded start and 30-second sync pulses to coordinate this effort.

SECTION 4

DATA COLLECTION SYSTEM

THE FIXED SITE

The single most important item in EQR's coordinated meteorological data gathering effort in the Anclote Keys plume study was the establishment of a centralized facility providing telemetered weather observations, essential to the operational forecasting of winds and weather, a radio communication network to monitor the progress of all airborne research and EQR meteorological teams, and a site at which to collect pibal and radiosonde data. EQR also supplied an Air Pollution Meteorologist who acted as the coordinator for all meteorological data gathering at the fixed site and at all remote locations.

The fixed site consisted of a 10 m trailer anchored just east of Tarpon Lake (Fig. 1) about 30 kilometers southeast of the Anclote Power Plant. The trailer was equipped with 110 and 220 volt power drops, two phone lines, and three long-line channels carrying weather information. The interior of the trailer was partitioned to accomodate a 403MHz radiosonde receiving station, a communications table with FM air to air and air to ground radios, wall display for weather maps to assist the Forecaster in making operational decisions, a storage area for all expendable items, two teletypes with surface and upper air meteorological data, and a weather map facsimile machine.

The exterior of the trailer was used to mount the antennas for the 403MHz radiosonde receiver, and the two radio systems. The interior of a twenty-foot truck was used to inflate the 100-gram weather balloons which carried the radiosonde packages. Fifty T-sized helium tanks were stored outside the trailer.

THE RADIOSONDE SYSTEM

Upper air sounding data was necessitated by the nature of the airborne

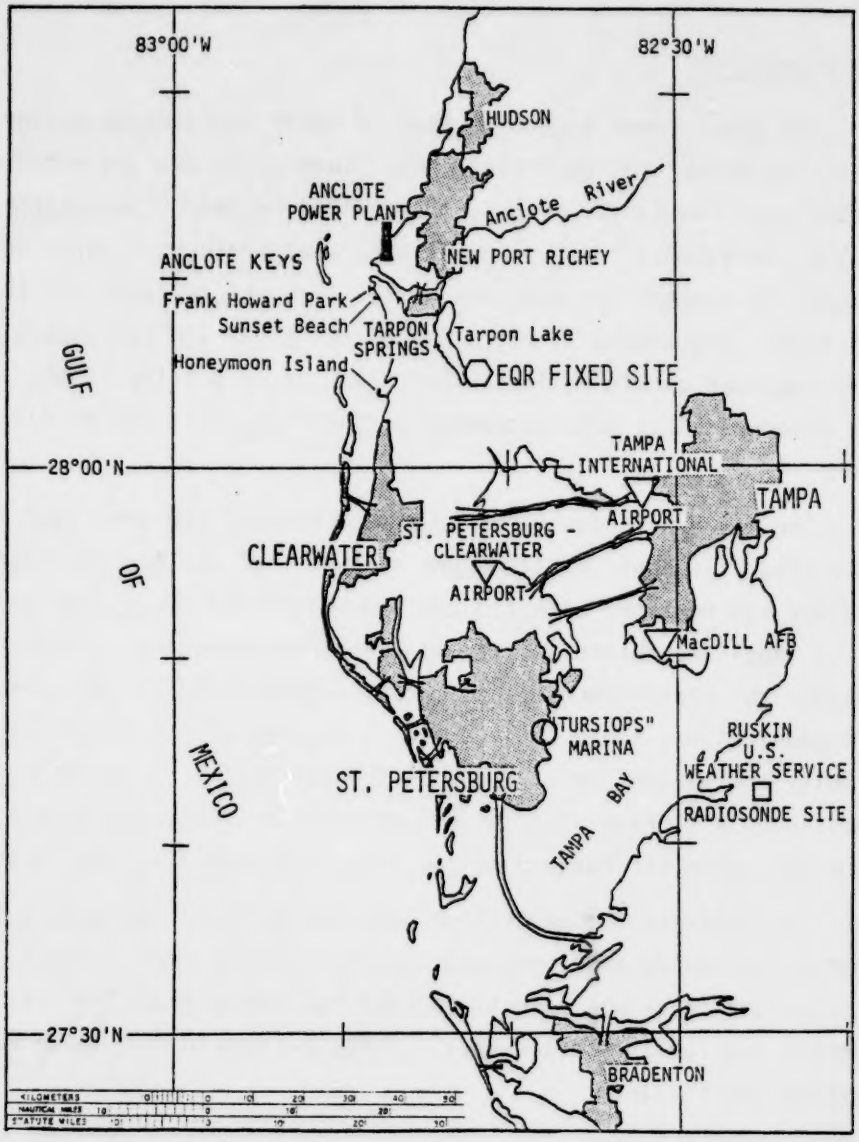

FIGURE 1. Key features and sites near Tampa, Florida.

experiment. Temperatures, humidity, and winds were needed on a six hourly basis up to 700 mb (10,000 feet or approximately 3000 meters). The 403MHz radiosonde system made by the VIZ Manufacturing Company, consists of an airborne package with an aneroid barometer, a white coated thermistor, a carbon hygristor, an adjustable 403MHz radio transmitter, a 100-gram lift balloon, and an AN/TMQ5 radiosonde recorder and antenna system which transcribes a time multiplexed data stream. The balloon and instrument package were tracked visually by theodolite so that wind speed and direction could be calculated. At night small lights were attached and tracked.

The 403MHz radiosonde system is a standard National Weather Service sounding instrument and all operating procedures were done in strict conformation with the Federal Meteorological Handbook #3 (Radiosonde Observations), the Federal Meteorological Handbook #5 (Winds-Aloft Observations), and the EPA approved Reference Manual for Low-Level Radiosonde and Pibal Soundings published in conjunction with the St. Louis EPA Regional Air Pollution Study (RAPS).

Following the guidelines for low level (700 mb) soundings the trending of the recorder traces produces $\pm 1°C$ accuracy in temperature profile and $\pm 5\%$ (RH > 20%) accuracy for the humidity trace.

THE PIBAL SYSTEM

Five high-resolution precision theodolites were deployed, one at the fixed site and four others at varying locations around the Anclote power plant. These sites are shown in Section 5. Azimuth and elevation angles are exact to 0.1° and can be interpolated to $\pm .01°$.

Pibal balloons were 10 and 30 gm and their positions were monitored at 30-second intervals. This technique produces averaged winds for approximately 64-meter levels (90 meters for 30-gram balloons) assuming standard ascent rates.

Pibal operators were mobile and set up at their sites before flight operations began. Pibal operations included a two-man crew operating a double pibal site, the first week on Anclote Keys, 10 kilometers due west of the Anclote power plant, and the second week on two coastal peninsulas 6 kilometers south of the plant.

The double pibal sites sought to provide more accurate winds since the balloon heights can be derived at each of the 30-second intervals. Accurate baselines of 629 meters and 1776 meters and baseline orientations were established trigonometrically using USGS maps and theodolite sightings from the double pibal locations.

TETHERSONDE DATA COLLECTION SYSTEM

The TETHERSONDE meteorological data collection system consists of a $3.25m^3$ blimp-shaped balloon, a portable winch, a computerized ground station, and an airborne instrument package. The instrument package measures temperature and wet bulb directly using precision bead thermistors. Surface pressure differential, up to 100 mb, is measured using an aneroid strain guage. Wind speed is monitored using a cup anemometer. Wind direction can be determined using an onboard magnetic compass since the shape of the balloon keeps the instrument package oriented into the wind.

Circuitry of the 5 sensors is contained in a single printed circuit board within the airborne package. The package is battery operated using a rechargeable 12 volt system with a 4-hour lifetime. The telemetry system consists of a narrow-band, crystal-controlled transmitter and receiver. Data are transmitted at 403MHz in two formats over separate channels. One is an FM-FM PAM time multiplexed format which may be recorded immediately on a single strip chart or on audio magnetic tape or on both simultaneously. The second format transmits data from one selected sensor continuously in FM-FM. A data frame with time multiplexed format consists of a wide sync pulse whose amplitude is full scale, followed by eight sensor channels separated by zero reference values.

The ground station receiver contains two audio FM discriminators, one for each channel. Due to the greater than 10 kilometer displacement between the 403MHz radiosonde and TETHERSONDE system, no signal interference was noticed at any time. An integral speaker lets the user monitor the signal aurally. An 8-bit microcomputer (INTEL, 8080A) in the ground station provides computer-compatible real-time data directly to a computer. The data may be further processed, printed in real time, or recorded for later processing.

Two 25-pin connectors permit the transfer of data in several modes. One

connector provides RS-232C and 20ma signal levels for CRT or teletype listing of digital data. The second provides control signals to a printing HP-97 calculator (or other models).

The winch can be powered by a built-in rechargeable battery or by external power sources. The winch is light-weight (25kg) and contains 1000 meters of high-tensile strength cord (90.7 kg test). This provides enough strength to withstand 20 m/sec wind stress and low enough weight to provide full 1 km extension of the tether package. However the TETHERSONDE system was originally designed at maximum 10 m/sec scale readout such that wind speeds higher than 10 m/sec caused severe signal distortion in all channels. The system has since been modified to a 20 m/sec limitation.

The tether balloon is cigar shaped with three aerodynamic ear fins for orientation stability. The instrument package is suspended using double guy lines to ensure fixed orientation with the balloon. The ground guy line is attached to the front of the balloon to provide maximum stability. The instrument package itself weighs about 1 kg. The fully inflated tether balloon has about a 2.2 kg lift.

The sensor specifications are given in Table 1.

TABLE 1. TETHERSONDE (TS-1A) SENSOR SPECIFICATIONS

	Range	Precision	Resolution	Type
Dry and Wet Bulb (Asperated)	-50°C to +50°C	±0.5C	0.1°C	Bead Thermistor
Differential Barometric Pressure	0 to 100 millibars	±1.0 millibars	0.5 millibars	Aneroid Strain Guage
Wind Speed (horizontal)	0.5 to 10 meters/sec	±0.25 meters/sec	0.1 meters/sec	Cup Anemometer
Wind Direction (Magnetic)	0° to 360°	±5°	2°	Magnetic Compass

SECTION 5

EXPERIMENTAL PROCEDURES

PRELIMINARY

One EQR employee arrived in Tampa Jan 27 to initiate the assembly of the fixed site. Six other EQR personnel arrived on Feb 5 and 6 to deploy equipment and supplies and to assist in assembling the radio communications system.

EXPERIMENT #1 (MONDAY, FEB 7, 1977)

The first MRI flight (SMOG 1) (1536-1736 LST) produced a sampling checkout for all systems. The Brookhaven plane (SMOG 2) made early morning flights to determine plume characterization. All flights originated out of the St. Petersburg - Clearwater airport.

The first EQR single pibal crew was dispatched to a position (Site 1) along the coast 1 km north-northeast of the Anclote Power Plant (Fig. 2). The second pibal crew was directed to a location near the coast 5 to 10 km to the south (Site 2) selecting Honeymoon Isle State Park (connected by causeway to the mainland).

The double theodolite team (Site 3) was assigned to set up an operational baseline on Anclote Keys 10 km west of the Anclote Plant. Transportation by boat was utilized to carry crews and equipment to the island. No double pibals were taken during Experiment 1. The research vessel Tursiops, used as a mobile launching platform for the TETHERSONDE system, was not deployed. From its dock in St. Petersburg approximately 3-4 hours were needed to intercept the plume. The vessel's optimum position was preselected by the EQR Forecaster. One EQR employee, an EPA official, and several crewmen were aboard the vessel.

Radiosonde releases were begun at 0600 Monday, Feb 7, coincident with the first experiment day, and continued through Feb 9 at six hour intervals.

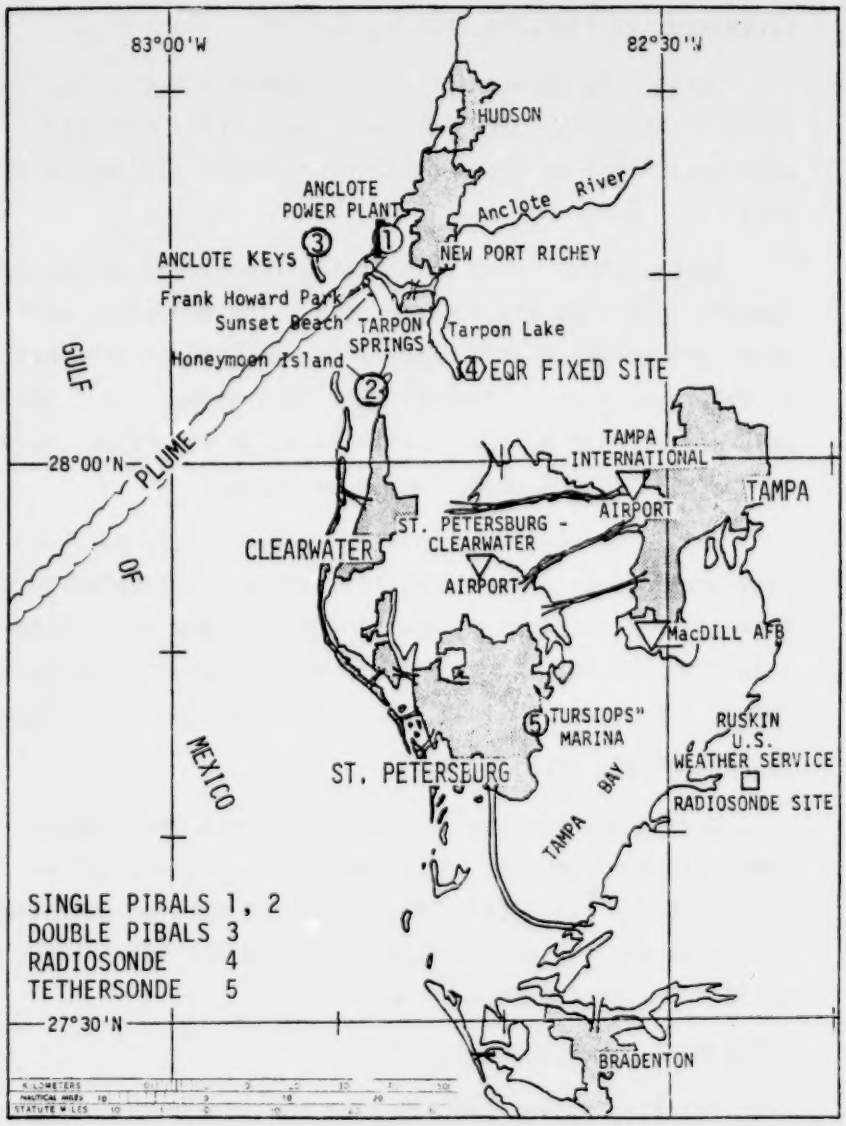

FIGURE 2. Locations of EQR meteorological crews for experiment 1, Feb 7, 1977. Plume location during the experiment is approximated.

Due to excess depletion of consumables, notably helium and 100-gram balloons, due to inferior balloon quality, the releases were rescheduled for 0000 and 1200 LST with the Ruskin Weather Service soundings, available over the Circuit "C" teletype, suppling the local meteorological soundings at 0600 and 1800 LST. Releases were continued at the EQR fixed site through Feb 18 (0000 LST), the last experiment day.

EXPERIMENT #2 (TUESDAY, FEB 8, 1977)

During the experiment plume characterization was done by the MRI SMOG 1 (1323 - 1655 LST). EQR personnel were fully deployed. Single pibal crews were positioned at the Anclote Power Plant and upwind in New Port Richey (Fig. 3).

Double pibal crews established themselves at the northern end of the largest island of the Anclote Keys. The two crews were aligned almost north-south 629 meters apart. Operations were terminated early to allow the crews to return by boat to the mainland during daylight. Anclote Keys were totally uninhabited with no public facilities of any kind. No docking facilities were available and boats had to be beached.

The TETHERSONDE experienced an electronic malfunction which detonated a slow leak safety device which is pressure activated to bring the instrument package back to earth if the line breaks and the package ascends to higher than 1000 meters. Several hours were needed to locate the malfunction and to repair the tether balloon. No usable readings were taken.

EXPERIMENT #2A (FEB 10, 1977)

During the morning of the 10th it was anticipated that Brookhaven Labs (SMOG 2) would monitor the plume. One single pibal was positioned at the Anclote Power Plant (Fig. 4) during the morning and afternoon. The other single pibal, the double pibal crew and the TETHERSONDE were not deployed until later in the day.

EXPERIMENT #3 (FEB 10-11, 1977)

MRI flights were anticipated for late night and early morning to accomplish plume sampling and special NO_x sampling. A single pibal crew was sent to the Anclote Power Plant. The double pibal crew was helicoptered to the

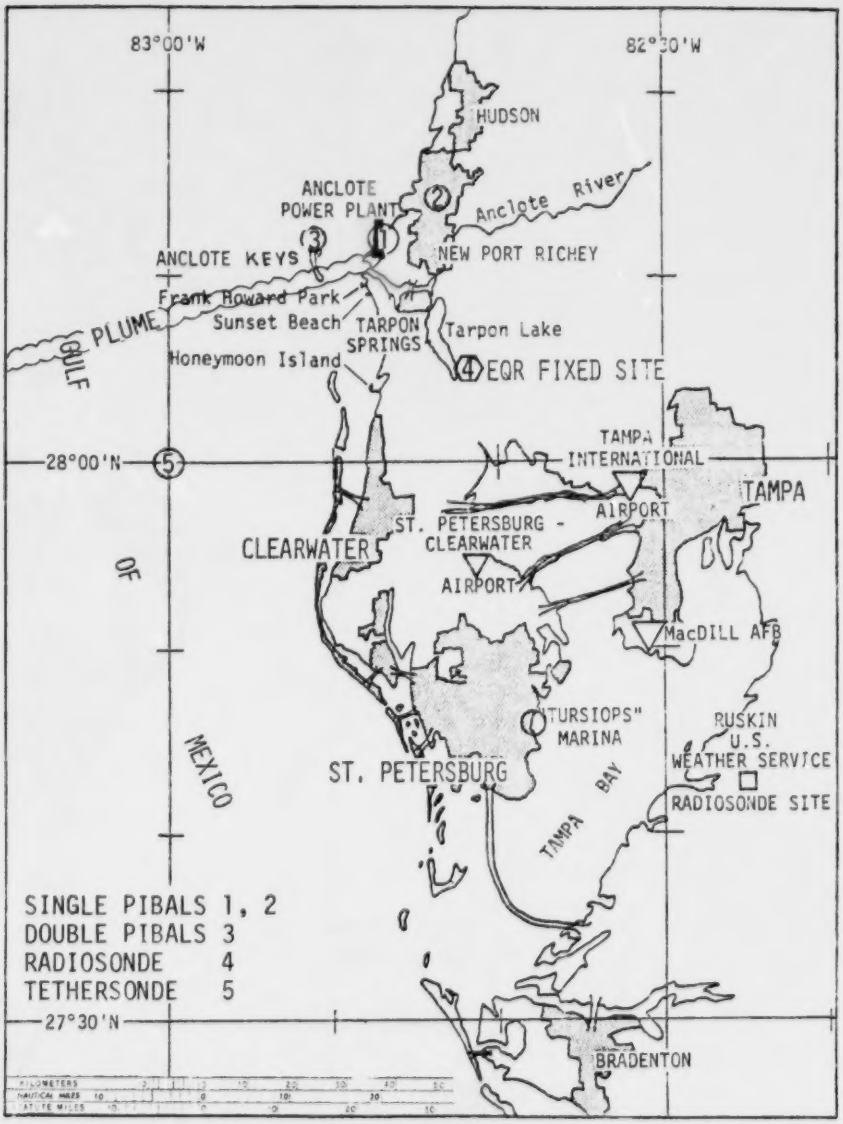

FIGURE 3. Locations of EQR meteorological crews for experiment 2, Feb 8, 1977. Plume location during the experiment is approximated.

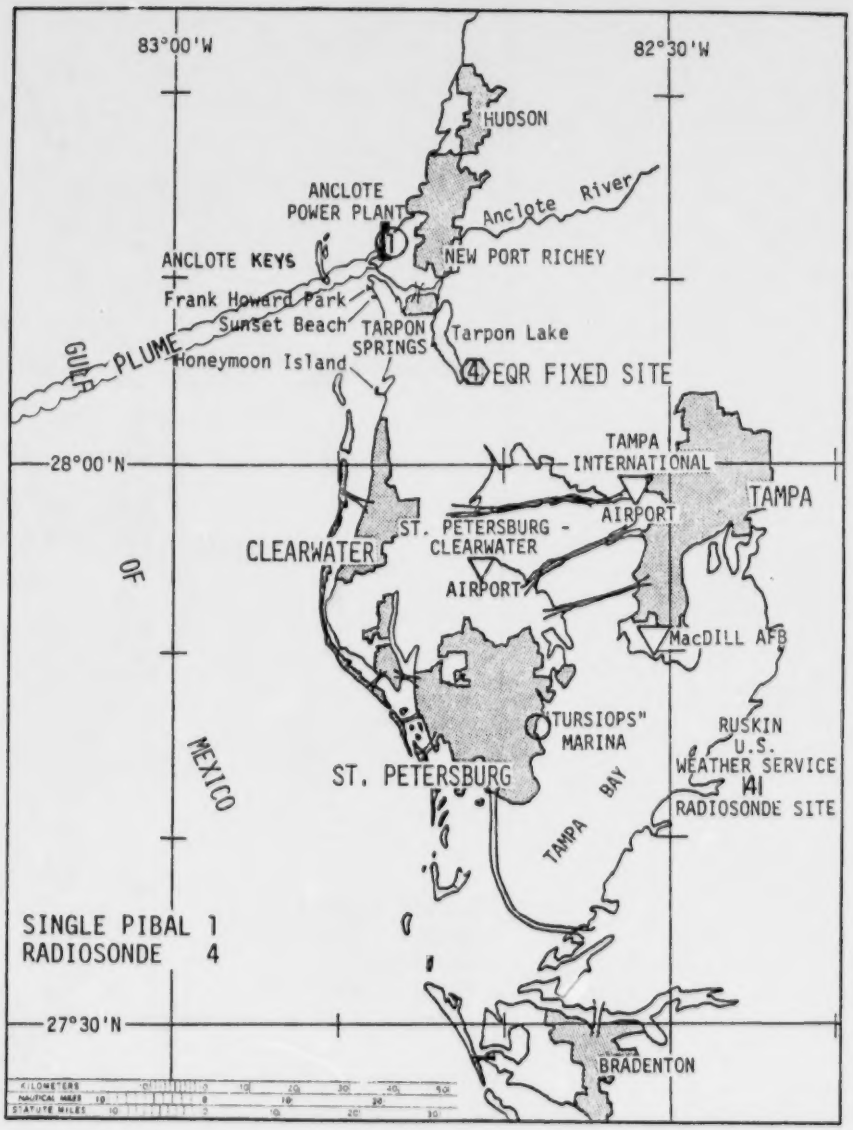

FIGURE 4. Locations of the EQR meteorological crews for experiment 2A, Feb 10, 1977. Plume location during the experiment is approximated.

Anclote Keys site after sunset. Communication difficulties between the two crews made simultaneous reading impossible so that only single pibals were taken.

The TETHERSONDE location was about 60 kilometers WSW of the Power Plant and 10 kilometers south of the plume. Sounding altitudes were limited by a low-level wind speed maximum that produced winds greater than 10 meters per second as low as 200 meters.

EXPERIMENT #4 (FEB 11, 1977)

During the late afternoon MRI scheduled an additional plume characterization and NO_x bubbler experiment. A single pibal site was deployed to the Anclote Power Plant. Lack of ground communications delayed this operation.

During the morning the double pibal crew was brought to the Tursiops anchored off Anclote Keys. After resting and gathering supplies the crew redeployed on the island. The TETHERSONDE was moved to about 35 kilometers south-southwest of the Anclote Power Plant and about 10 kilometers west of the plume. Once again wind speeds in excess of 10 meters per second restricted altitudes to less than 200 meters.

EXPERIMENT #5 (FEB 12, 1977)

Experiment 5 provides an opportunity to do sunrise sampling and to chase the plume in excess of 100 kilometers. EQR had all personnel deployed. Single pibal crews were sent to the Anclote Power Plant and to an upwind location at the EQR fixed site near Tarpon Lake.

The double pibal crew remained on the Anclote Keys overnight and began operations before sunrise. The crew and equipment were again moved by helicopter at the experiment's conclusion to the EQR fixed site. Helium supplies were subsequently loaded aboard the Tursiops.

The Tursiops did not redeploy to a point northwest of the Power Plant in accordance with forecast information available the night before. Repair of a leakage in the tether balloon necessitated a late start, and continued gas loss limited flights to 100 meters.

EXPERIMENT #6 (FEB 15, 1977)

Due to a sea breeze which transported the Anclote plume inland across

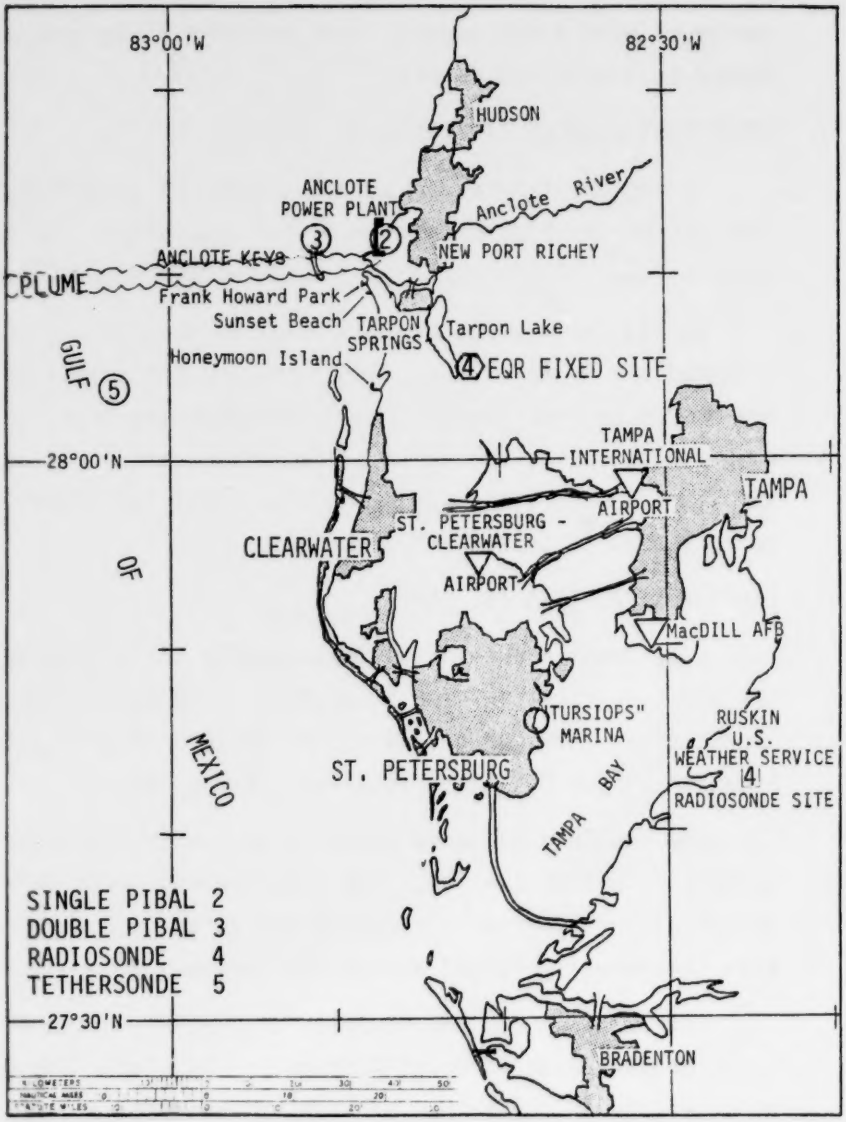

FIGURE 5. Locations of the EQR meteorological crews for experiment 3, Feb 10-11, 1977. Plume location during the experiment is approximated.

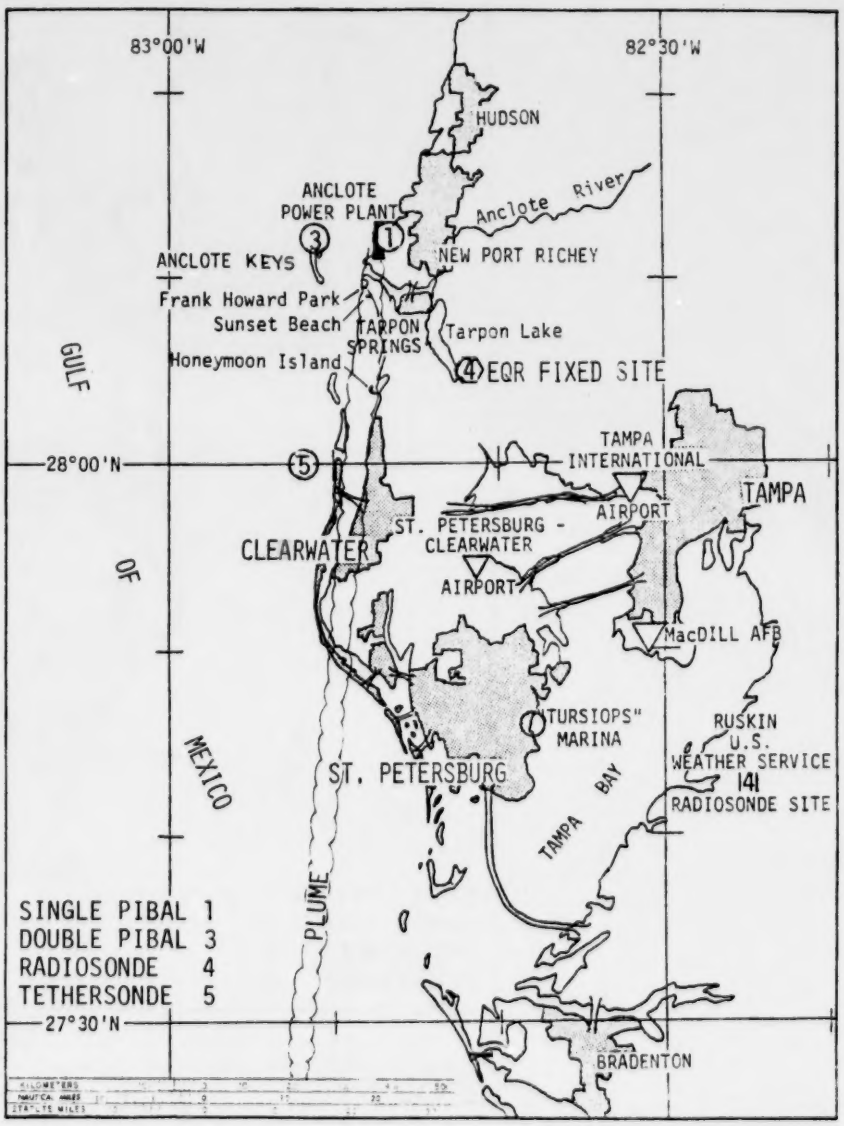

FIGURE 6. Locations of the EQR meteorological crews for experiment 4, Feb 11, 1977. Plume location during the experiment is approximated.

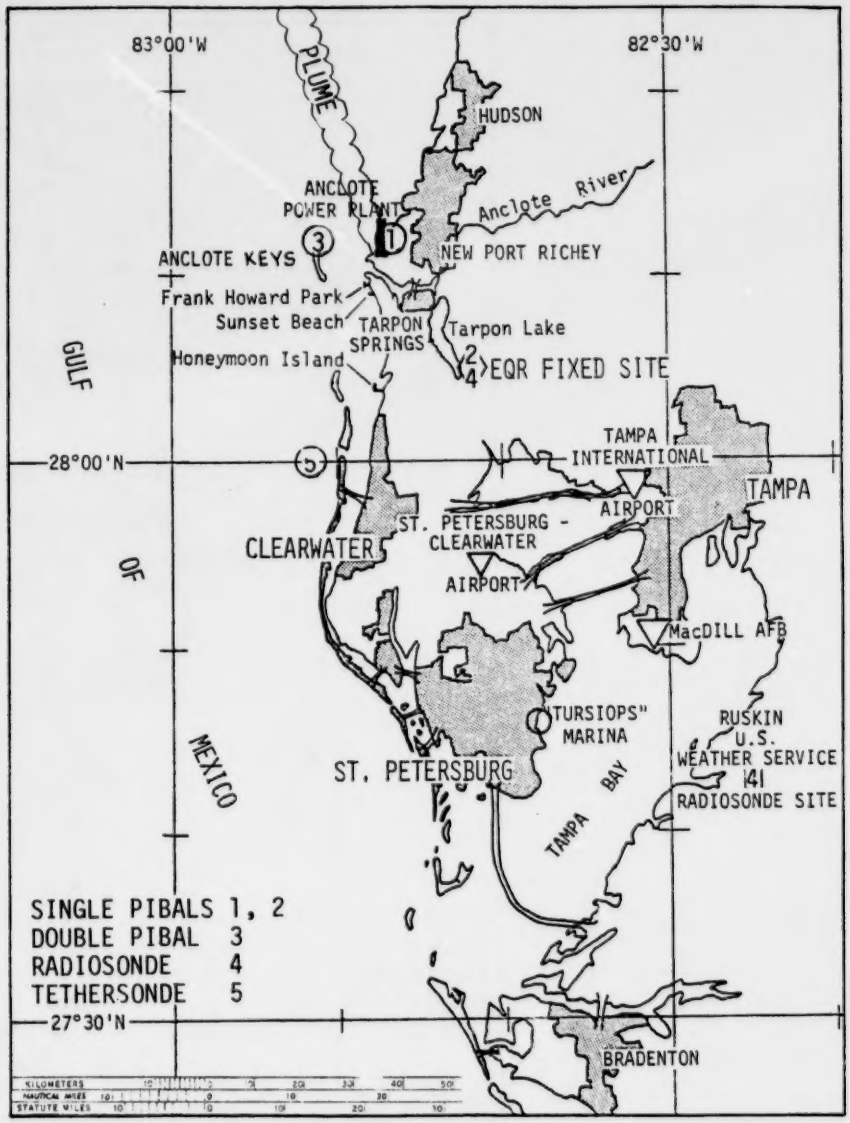

FIGURE 7. Locations of the EQR meteorological crews for experiment 5, Feb 12, 1977. Plume location during the experiment is approximated.

the populated Tampa area, MRI ran a cross-comparison flight close to the power plant with Brookhaven Laboratories. EQR single pibals were deployed inland and downwind of each other to a position north of the plume and away from Tampa Bay. Single pibal crews remained at these sites until the conclusion of the experiment.

The double pibal crew redeployed on the Gulf coast using a man-made island (Howard Park) connected by causeway to the coast and a peninsula (Sunset Beach) as new positions for a baseline (Fig. 8). Baseline orientation and distance were fixed during the interval between Experiments 5 and 6. The double pibal sites were approximately 6 kilometers south-southwest of the Anclote Power Plant and were 1776 meters apart. Orientation of the two points were WNW-ESE.

Meteorological conditions permitted optimum TETHERSONDE operations throughout the whole experiment. The Tursiops was anchored several kilometers off the south end of Anclote Keys. TETHERSONDE ascents to greater than 500 m were accomplished.

EXPERIMENT #6A (FEB 16, 1977)

On the evening of Feb 15, 1977, it was decided to deploy EQR personnel in anticipation of a MRI (SMOG 1) flight the following morning although forecast wind conditions were not favorable. Early morning preliminary meteorological data taken by the crews confirmed unfavorable conditions and the flight was cancelled.

EXPERIMENT #7 (FEB 17, 1977)

The morning experiment on Feb 17 was used to measure fallout underneath the Anclote Power Plant plume. The MRI SMOG 1 flight stayed within 20 kilometers of the plant. One single pibal was put at the Anclote Plant and another at the EQR fixed site. No attempt was made to gather downwind data due to the close proximity of the SMOG 1 sampling to the plant.

The double pibal crews were again set up along Howard Park - Sunset Beach baseline. TETHERSONDE operations were suspended while crew and supplies were being boarded out of Tarpon Springs.

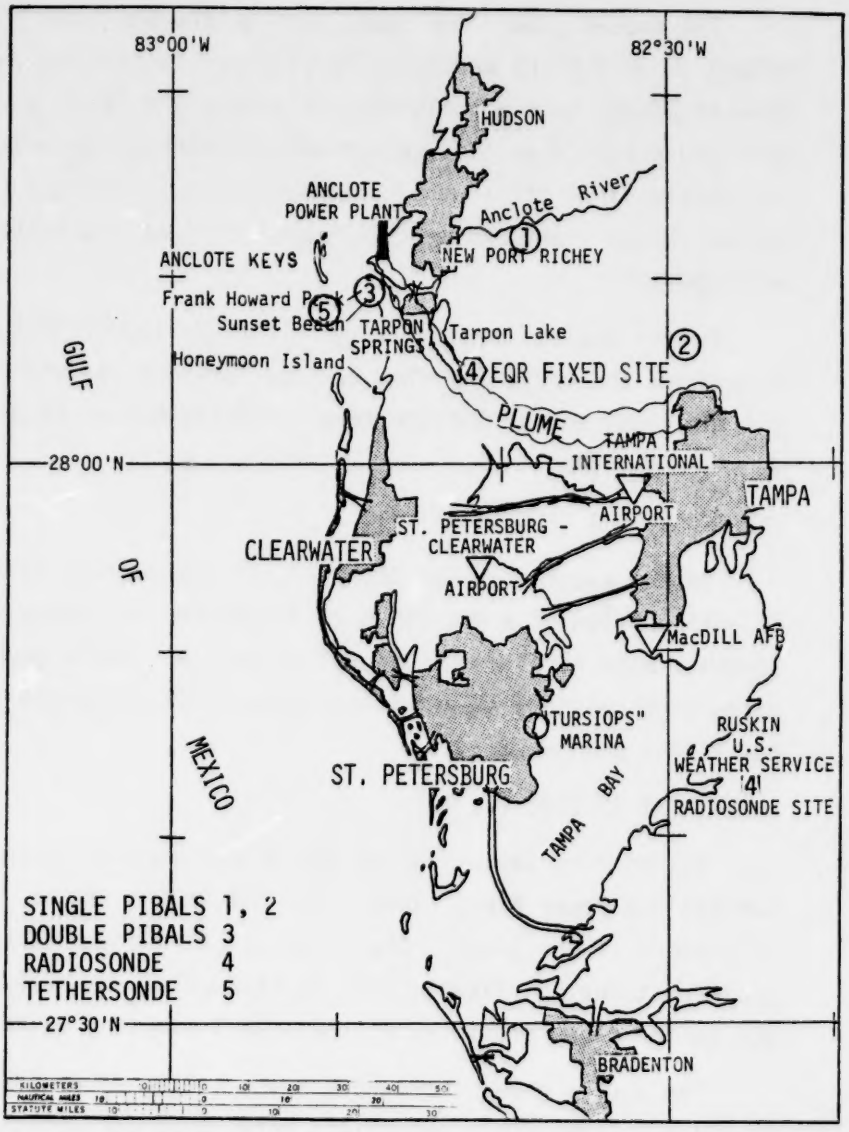

FIGURE 8. Locations of the EQR meteorological crews for experiment 6, Feb 15, 1977. Plume location during the experiment is approximated.

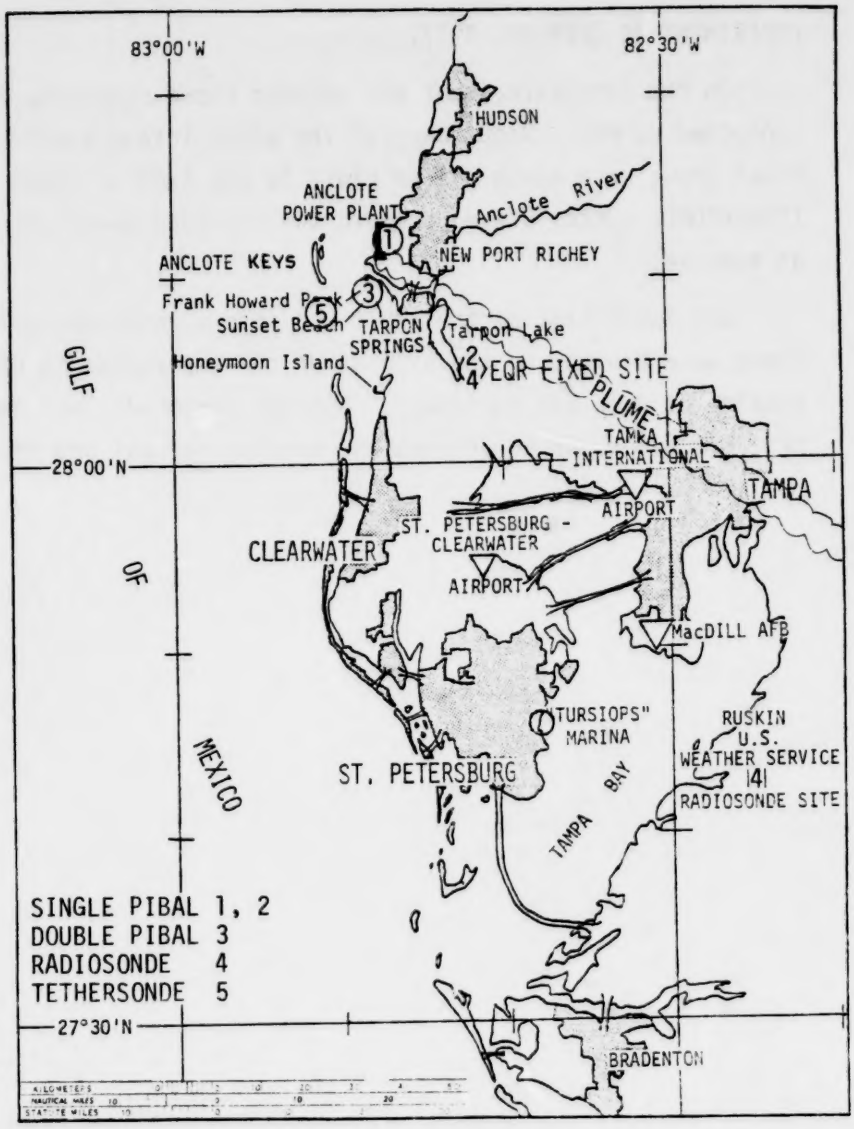

FIGURE 9. Locations of the EQR meteorological crews for experiment 6A, Feb 16, 1977. Plume location during the experiment is approximated.

EXPERIMENT #8 (FEB 17, 1977)

Close proximity flights were continued on the afternoon of the 17th with SMOG 1 running plume characterizations. All EQR pibal crews maintained their locations the entire day. The TETHERSONDE operations reached an altitude over 400 meters.

EXPERIMENT #9 (FEB 18, 1977)

On the last experiment day another close proximity fallout study was conducted by MRI. Winds carried the plume inland toward the north-northeast. Pibal crews were again placed close to the Anclote Power Plant. The TETHERSONDE system stayed onboard the Tursiops overnight and began operations at sunrise.

All facilities at the EQR fixed site were disassembled Feb 18. All crews were brought to the site after the experiment to effect tear down and packing of data and equipment. All EQR personnel left Tampa Feb 19 except the Forecaster who supervised the trailer removal and site clean-up.

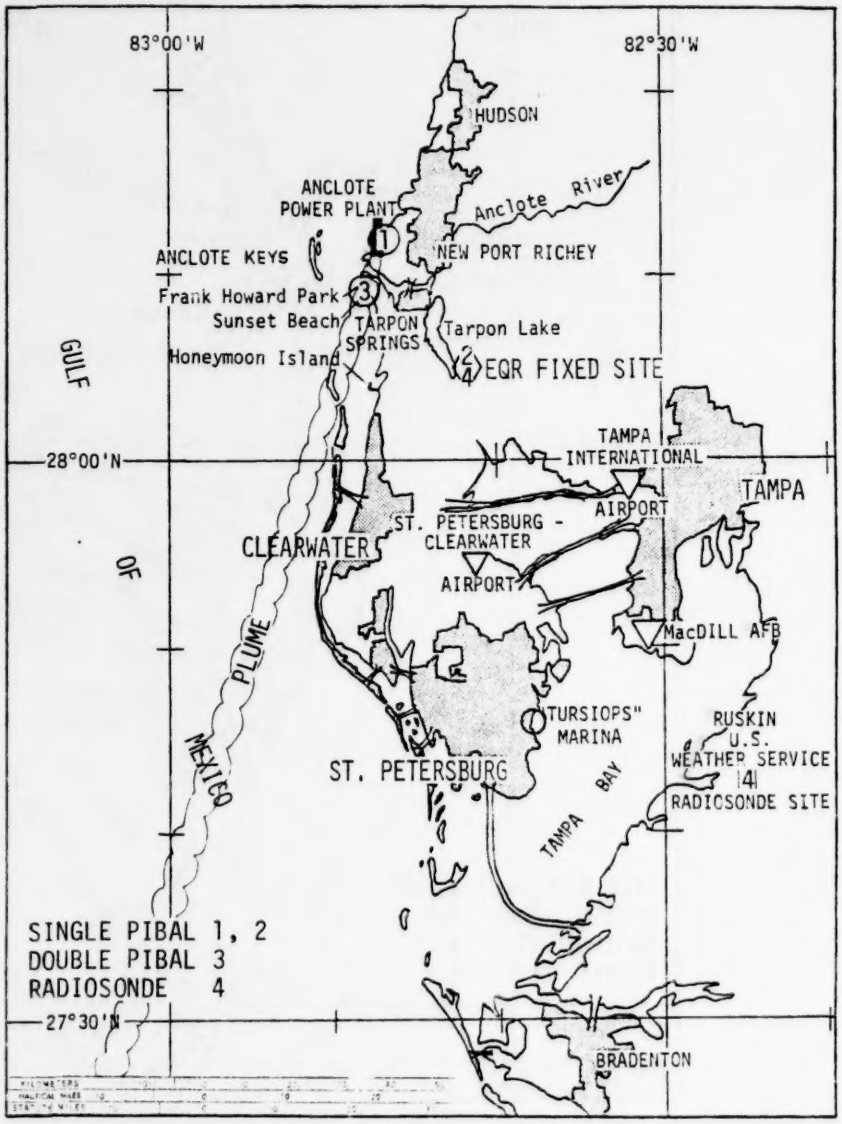

FIGURE 10. Locations of the EQR meteorological crews for experiment 7, Feb 17, 1977. Plume location during the experiment is approximated.

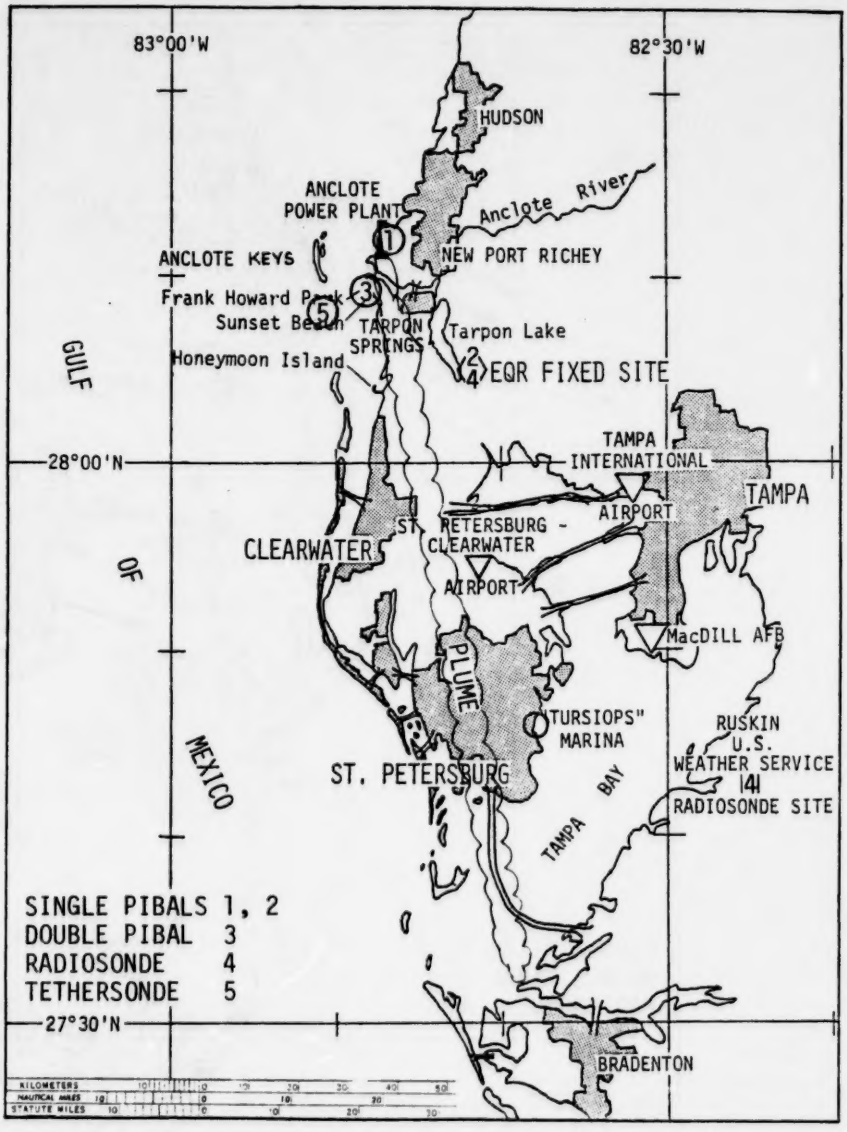

FIGURE 11. Locations of the EQR meteorological crews for experiment 8, Feb 17, 1977. Plume location during the experiment is approximated.

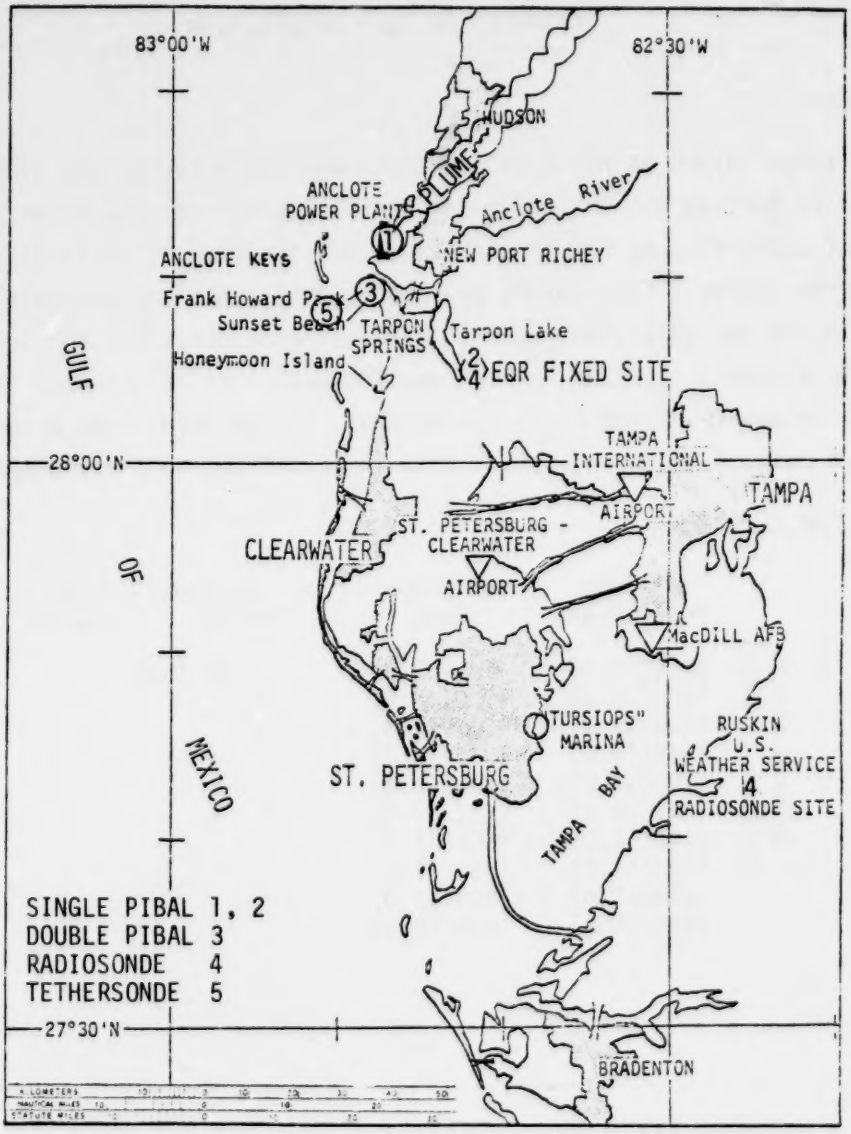

FIGURE 12. Locations of the EQR meteorological crews for experiment 9, Feb 18, 1977. Plume location during the experiment is approximated.

SECTION 6

SCHEDULES OF DATA ACQUISITION

PIBAL DATA

A large volume of pilot balloon data was collected at the sites described in Section 5. The following lists of pibal release times include releases authorized by EPA personnel but not included in officially designated experiments. Each column of numbers designates balloon release times (LST), while the adjoining numbers in parantheses describes the length of time (in minutes) that the balloon was tracked. The location of the pilot balloon release is given above the column. Single pibal data occupy the left two columns and double pibal data are described in the right two columns.

Monday Feb 7, 1977

Release times (Minutes of Data)	Anclote Power Plant	Honeymoon Island	Anclote Island North	Anclote Island South
	0910(10.5)	1100(12.0)	NO DATA	
	1000(14.5)	1130(12.0)		
	1030(12.0)	1200(12.0)		
	1115(14.0)	1230(12.0)		
	1200(11.0)	1300(12.0)		
	1245(10.5)	1332(12.0)		
	1440(12.0)	1500(12.0)		
	1500(14.0)	1530(12.0)		
	1610(12.0)	1600(12.0)		
	1655(15.0)	1630(10.5)		

Tuesday Feb 8, 1977

Release times (Minutes of Data)

New Port Richey	Anclote Power Plant	Anclote Island North	Anclote Island South
1140(14.0)	1000(12.0)	1313(5.0)	1313(3.5)
1205(7.0)	1030(12.0)	1341(12.0)	1341(12.0)
1240(8.0)	1100(11.5)	1423(12.0)	1423(3.5)
1305(7.0)	1130(12.0)	1505(12.0)	1505(12.0)
1345(2.0)	1200(12.0)		
1348(3.0)	1330(12.0)		
1440(0.5)	1400(12.0)		
1444(0.5)	1430(12.0)		
1448(1.0)	1502(12.0)		
1453(3.5)	1530(12.0)		
1515(18.5)	1600(12.0)		
1604(4.0)	1630(12.0)		
1620(12.5)	1700(12.0)		
1658(11.0)			

Thursday Feb 10, 1977

Release times (Minutes of Data)

Anclote Power Plant	Anclote Power Plant	Anclote Island North	Anclote Island South
815(5.0)	2202(12.0)	2335(17.0)	
835(7.0)	2230(12.0)		
900(8.5)	2315(12.0)		
936(10.5)	2359(12.0)		
1002(20.5)			
1035(4.5)			
1045(4.0)			
1115(6.5)			
1205(13.5)			
1410(12.0)			
1506(8.0)			
1533(1.5)			
1545(12.0)			
1610(13.0)			
1630(11.5)			
1710(14.0)			
1738(10.5)			
1800(16.8)			
1835(0.5)			
1905(11.0)			
1953(15.0)			

Friday Feb 11, 1977

Releast times (Minutes of Data)

Anclote Power Plant	Anclote Power Plant	Anclote Island North	Anclote Island South
1930(14.0)	0030(12.0)	0035(12.0)	
2003(13.5)	0106(12.0)	0115(12.0)	
	0215(5.5)		0232(13.0)
			1532(8.5)
		1600(11.0)	1600(2.5)
		1630(10.0)	1630(10.5)
		1658(13.0)	1658(12.5)
		1730(12.0)	1730(12.0)
		1800(12.0)	1800(12.0)
		1830(14.0)	1830(13.0)
		1915(20.0)	1915(0)

Saturday Feb 12, 1977

Release times (Minutes of Data)

EQR Fixed Site	Anclote Power Plant	Anclote Island North	Anclote Island South
0734(7.5)	0500(12.0)	0535(5.0)	
0800(15.5)	0530(12.0)	0653(8.0)	0653(9.0)
0830(9.0)	0600(12.0)	0731(15.0)	0731(10.0)
0902(10.5)	0630(12.0)	0800(11.0)	0800(12.0)
0930(12.0)	0707(2.0)	0830(12.0)	0830(12.0)
1002(12.0)	0730(12.0)	0903(12.0)	0903(12.0)
1033(7.5)	0800(12.0)	0934(9.5)	0934(14.0)
1107(3.5)	0830(12.0)	1000(11.5)	1000(12.0)
	0900(12.0)	1100(15.0)	1058(12.0)
	0930(12.0)		
	1000(10.5)		
	1030(12.0)		
	1100(12.0)		
	1133(12.0)		
	1200(12.0)		
	1230(12.0)		
	1300(8.5)		
	1330(10.5)		

Tuesday Feb 15, 1977

Release times (Minutes of Data)	Odessa, Florida	Fla 582 at US 301	Howard Park	Sunset Beach
	1210(5.5)	1300(7.5)	1146(12.0)	
	1233(7.0)	1330(11.5)	1231(12.0)	1231(9.5)
	1300(5.5)	1400(12.0)	1300(12.0)	1300(12.0)
	1331(9.0)	1430(12.0)	1330(12.0)	1330(12.0)
	1406(10.5)	1505(12.0)	1400(12.5)	1400(12.0)
	1432(12.5)	1530(12.0)	1430(1)0	1430(12.0)
	1505(12.0)	1600(12.0)	1500(12.0)	1500(12.0)
	1600(13.5)	1630(12.0)	1530(12.0)	1530(12.0)
	1637(10.5)	1700(8.5)	1600(11.5)	1600(12.0)
	1701(12.0)	1730(12.0)	1630(12.0)	1630(12.0)
	1730(12.0)		1700(12.0)	1700(12.0)
			1730(11.0)	1730(11.0)

Wednesday Feb 16, 1977

Release times (Minutes of Data)	Anclote Power Plant	EQR Fixed Site	Sunset Beach	Howard Park
	1330(7.5)	NO DATA	1203(0)	1203(8.5)
			1230(10.0)	1230(10.5)
			1300(2.0)	1300(0.5)
			1305(7.0)	1305(8.0)
			1330(5.0)	1330(0.5)

Thursday Feb 17, 1977

Releast times (Minutes of Data)	Anclote Power Plant	EQR Fixed Site	Sunset Beach	Howard Park
	0542(3.5)	0512(3.5)	0600(6.0)	0600(8.5)
	0601(6.5)	0539(12.0)	0635(8.0)	0635(0.5)
	0708(3.5)	0630(7.5)	0700(0.5)	0700(1.0)
	0732(6.0)	0700(12.0)	0708(6.5)	0708(0.5)
	0817(8.5)	0730(6.0)	0730(12.5)	0730(12.5)
	0832(10.0)	0800(9.0)	0800(8.0)	0800(6.0)
	0904(8.0)	0830(6.0)	0830(7.5)	0830(8.0)
	0939(7.0)	0900(7.5)	0900(5.0)	0900(7.5)
	1130(11.5)	0930(12.0)	0930(8.5)	0930(7.5)
	1203(12.0)	1144(10.0)	1137(10.5)	1137(9.0)
	1230(8.0)	1202(12.5)	1205(11.0)	1205(11.5)
	1312(11.5)	1230(14.0)		1242(9.5)
	1337(9.5)	1300(12.0)		1328(6.0)
	1400(5.0)	1330(9.5)	1346(8.5)	1346(10.0)
	1435(6.5)	1400(12.0)	1430(11.0)	1430(10.0)
	1500(4.5)	1430(12.0)	1500(11.0)	1500(10.5)
	1510(12.0)	1500(10.0)	1530(11.0)	1530(11.5)
	1532(10.0)	1535(5.5)	1600(5.0)	1600(0)
	1600(11.5)	1606(12.0)	1630(12.0)	1630(0)
	1645(14.0)	1630(11.0)		
	1704(9.5)			

Friday Feb 18, 1977

Releast times (Minutes of Data)	Anclote Power Plant	EQR Fixed Site	Sunset Beach	Howard Park
	0709(13.0)	0610(6.0)	0610(12.0)	
	0733(10.0)		0700(2.5)	0700(1.0)
	0800(5.0)		0707(9.5)	0707(3.0)
	0830(2.5)		0735(9.5)	0735(12.0)
	0836(6.5)		0800(8.0)	0800(11.0)
	0901(9.5)		0830(9.5)	0830(1.5)
	0930(11.0)		0900(9.0)	0900(2.0)
	1000(4.5)		0930(10.0)	0930(4.5)
	1031(9.0)		1000(9.5)	1000(10.0)
	1100(5.0)		1030(0)	1030(9.0)
			1100(0)	1100(0.5)

TETHERSONDE DATA

TETHERSONDE operations were conducted as described in Section 5 and continued as long as prescribed operational limitations were not exceeded. The following tables give the amount of data taken during each experiment and denote chronologically the various ascents and descents of the instrumented package. Each ascent or descent is ascribed a run number. The initial and final height of each run as well as its start, and stop time, are listed. The duration gives the length of time that useable data were obtained during each run. Total ascent and descent times are accumulated for each experiment.

Experiment #1, Feb 7, 1977 (Tursiops Not Deployed)

Experiment #2, Feb 8, 1977 (28°00'N, 83°00'W)

Balloon detonation, no data acquired.

Experiment #3, Feb 10-11, 1977 (28°03'N, 83°03'W)

RUN NO	BEGIN RUN	END RUN	INIT HT(M)	END HT(M)	DURATION (HR:MIN)
041-1	2340.00	2352.50	0.00	175.73	0:12.50
042-1	0010.00	0021.00	177.19	217.41	0:11.00
042-2	0021.00	0030.00	217.41	176.23	0:09.00
042-3	0030.00	0042.00	176.23	199.72	0:12.00
042-4	0102.00	0140.00	201.81	94.54	0:15.00
				ASCENDING:	0:35.50
				DESCENDING:	0:24.00

Experiment #4, Feb 11, 1977 (28°00'N, 82°52'W)

RUN NO	BEGIN RUN	END RUN	INIT HT(M)	END HT(M)	DURATION (HT:MIN)
042-5	1846.00	1902.25	0.00	140.20	0:10.25
042-6	1930.00	1932.50	135.08	140.20	0:02.50
042-7	1932.50	1945.00	140.20	63.68	0:12.50
				ASCENDING:	0:13.75
				DESCENDING:	0:12.50

Experiment #5, Feb 12, 1977 (28°00'N, 82°53'W)

RUN NO	BEGIN RUN	END RUN	INIT HT(M)	END HT(M)	DURATION (HR:MIN)
043-1	1200.48	1203.54	0.00	68.14	0:03.06
043-2	1203.54	1208.16	68.14	11.55	0:04.62
				ASCENDING:	0:03.06
				DESCENDING:	0:04.62

Experiment #6, Feb 15, 1977 (28°08'N, 82°51'W)

RUN NO	BEGIN RUN	END RUN	INIT HT(M)	END HT(M)	DURATION (HR:MIN)
046-1	1150.38	1158.38	19.62	237.52	0:08.00
046-2	1242.32	1250.41	249.35	334.06	0:08.09
046-3	1310.00	1323.00	351.85	521.19	0:13.00
046-4	1347.88	1415.17	511.79	165.10	0:27.29
046-5	1415.17	1424.62	165.10	350.30	0:11.45
046-6	1437.67	1447.05	350.30	266.97	0:09.38
046-7	1447.05	1500.12	266.97	541.04	0:13.07
046-8	1500.12	1520.97	541.04	339.92	0:20.85
046-9	1520.97	1539.50	339.92	518.42	0:09.53
046-10	1600.11	1615.73	489.76	300.04	0:15.62
046-11	1647.00	1700.00	32.96	503.96	0:13.00
046-12	1700.00	1721.24	503.96	206.22	0:21.24
				ASCENDING:	1:16.14
				DESCENDING:	1:34.38

Experiment #7, Feb 17, 1977(Tursiops Not Deployed)

Experiment #8, Feb 17, 1977 (28°08'N, 82°51'E)

RUN NO	BEGIN RUN	END RUN	INIT HT(M)	END HT(M)	DURATION (HR:MIN)
048-1	1501.00	1524.00	63.26	402.98	0:23.00
048-2	1524.00	1602.50	402.98	8.57	0:30.50
				ASCENDING:	0:23.00
				DESCENDING:	0:30.50

Experiment #9, Feb 18, 1977 (28°08'N, 82°51'E)

RUN NO	BEGIN RUN	END RUN	INIT HT(M)	END HT(M)	DURATION (HR:MIN)
049-1	0817.00	0841.50	18.99	371.51	0:24.50
049-2	0900.25	1028.38	328.77	0.36	0:50.83
				ASCENDING:	0:24.50
				DESCENDING:	0:50.83

Total TETHERSONDE Operation

	DURATION (HR:MIN)
ASCENDING:	2:55.92
DESCENDING:	3:36.83

RADIOSONDE DATA

All radiosonde releases were made from the EQR fixed site located at the southeast end of Tarpon Lake about 30 kilometers southeast of the Anclote Power Plant. In addition, radiosonde information was obtained from the National Weather Service station at Ruskin, Florida, 130 kilometers southeast of the Anclote Plant. A composite table is shown below which lists all radiosonde data chronologically:

TABLE 2. A DESCRIPTIVE LIST OF ALL RADIOSONDE RELEASES TAKEN DURING THE ANCLOTE KEYS PLUME STUDY, FEB 1977

NO.	DATE	RELEASE TIME(LST)	LOCATION	MAX ALT(mb)	COMMENTS
A	2/5/77	1800	RUSKIN	700	-
B	2/6/77	0600	"	"	-
C	"	1800	"	"	-
1	2/7/77	0650	EQR SITE	779	Balloon burst
1	"	0600	RUSKIN	700	-
2	"	1220	EQR SITE	"	-
3	"	1858	"	"	-
3	"	1800	RUSKIN	"	-
4	2/8/77	0015	EQR SITE	820	Balloon burst
5	"	0635	"	700	-
5	"	0600	RUSKIN	"	-
6	"	1320	EQR SITE	"	2nd release, no winds recorder malfunction
7	"	1902	"	"	-
7	"	1800	RUSKIN	"	-
8	2/9/77	0020	EQR SITE	784	Lost signal
9	"	0605	"	700	-
9	"	0600	RUSKIN	"	-
10	"	1256	EQR SITE	sfc data	Release late, balloons bursting. Release in high winds ruptured balloon, no 2nd release; pibal winds taken
11	"	1757	RUSKIN	700	-

(TABLE 2 continued)

(TABLE 2 continued)

NO.	DATE	RELEASE TIME(LST)	LOCATION	MAX ALT(mb)	COMMENTS
12	2/10/77	0010	EQR SITE	700	-
13	"	0600	RUSKIN	"	-
14	"	1205	EQR SITE	928	Balloon burst, no 2nd release
15	"	1800	RUSKIN	700	-
16	2/11/77	0000	EQR SITE	"	No winds, theodolite fogged
17	"	0600	RUSKIN	"	-
18	"	1200	EQR SITE	-	No release, EQR crew needed elsewhere
19	"	1800	RUSKIN	700	-
20	2/12/77	0030	EQR SITE	700	No winds, time clock malfunction
21	"	0600	RUSKIN	"	
22	"	1205	EQR SITE	931	Balloon burst
23	"	1800	RUSKIN	700	-
24	2/13/77	0010	EQR SITE	"	-
25	"	0600	RUSKIN	-	Data not available
26	"	1347	EQR SITE	700	Balloons bursting; needed 2nd release
27	"	1800	RUSKIN	"	-
28	2/14/77	0005	EQR SITE	"	-
29	"	0600	RUSKIN	"	-
30	"	1200	EQR SITE	"	-
31	"	1800	RUSKIN	"	-
32	2/15/77	0010	EQR SITE	"	No winds, Theodolite fogged
33	"	0600	RUSKIN	"	-
34	"	1205	EQR SITE	"	-
35	"	1800	RUSKIN	"	-
36	2/16/77	0015	EQR SITE	732	Lost signal
37	"	0600	RUSKIN	700	-
38	"	1315	EQR SITE	"	Bad balloons; 2nd release necessary
39	"	1800	RUSKIN	"	-
40	2/17/77	0030	EQR SITE	"	-
41	"	0600	RUSKIN	"	-
42	"	1340	EQR SITE	"	Late due to balloons bursting during filling
43	"	1800	RUSKIN	"	-
44	2/18/77	0044	EQR SITE	"	-
45	"	0600	RUSKIN	"	-
46	"	1800	"	"	-

SECTION 7

DATA FORMATS

PIBAL DATA

All single and double pibal azimuth and elevation angles have been recorded on cassette tape at the time of observation. Between launches the data were transcribed onto data forms by the observer. The quality control of pibal data included listening to all tapes to corroborate the data and to scan closely all observations which might be considered questionable. These raw observations are not in the Appendix but are available from the Contractor.

The pibal data were worked up analytically in an HP-97 calculator to derive the average wind between 30-second observations. These wind speed and direction results were also transcribed onto the data forms which contained the raw angles.

Because pibal observations cannot be exactly spaced every 30 minutes and since erroneous data in individual pibal launches can pass through routine inspection, all pibal data were plotted graphically to construct a height-time cross-section at each individual site for each experiment. Data were plotted obliquely in the vertical to represent the passage of time during the pibal run. Wind speeds and directions were analyzed separately to provide a homogeneous presentation of data. Wind speed and direction data were interpolated at even 30-minute intervals and 100-meter levels from which the tables in Appendix A were constructed.

TETHERSONDE DATA

The TETHERSONDE—HP-97 data collection system described in Section 4 automatically produces a printout of the sampled meteorological variables at intervals ranging from 5 seconds to 5 minutes. Additional derived printouts can be obtained in real time at some sacrifice in the frequency of data sampling.

The printing HP-97 was programmed to produce 10 parameters during each data frame allowing sampling at a rate of 1 complete cycle per 40 seconds. The TETHERSONDE outputs are:

a. TIME - digital input from receiving station given hours, minutes, and tenths of a minute

b. PRES - pressure (millibars) derived by subtracting the measured incremental pressure drop from an inputed initial pressure (P_o)

$$P_i = P_o - \triangle P_i$$

c. TEMP - ambient temperature (°C) measured at the altitude of the instrument package (T_i)

d. HGT - instrument height (m) derived by adding the newly computed balloon height changes from the height of the previous instrument height $H_i = \triangle H_i + H_{i-1}$

where the incremental height ($\triangle H$) of the instrument package is derived using observed and previous temperatures and pressures

$$H_i = 29.27\ (\overline{T} + 273.15)\ \ln\left(\frac{P_{i-1}}{P_i}\right)$$

where $$\overline{T} = \frac{T_i + T_{i-1}}{2}$$

e. P TEMP - potential temperature is derived using the observed temperature and pressure

$$\theta_i = (T_i + 273.15)\left(\frac{1000}{P_i}\right)^{.286}$$

f. RH - relative humidity (percent) is derived from the measured temperature and wet bulb quantities

$$RH_i = \frac{100\ e_i}{e_{s,i}}$$

where $e_{s,i}$ is the vapor saturation pressure at temperature T_i (C°),

$$e_{s,i} = 6.1078 \times 10^{\left(\frac{7.5\ T_i}{237.3 + T_i}\right)}$$

$e_{sw,i}$ is the saturation vapor pressure at wet bulb temperature $T_{w,i}$ (C°),

$$e_{sw,i} = 6.1078 \times 10^{\left(\frac{7.5\ T_{w,i}}{237.3 + T_{w,i}}\right)}$$

and $e_i = e_{sw,i} - 6.6 \times 10^{-4} (1 + .0015\ T_{w,i})(P_i)(T_i - T_{w,i})$

where $(T_i - T_{w,i})$ is the wet bulb depression

g. DEW PT - dew point (°C) is derived from the humidity and temperature (valid for pressures 900 - 1100 mb)

$$DP_i = \frac{-5380}{\ln(\frac{RH_i}{100}) - \frac{5380}{T_i + 273.15}} - 273.15$$

h. MIX - mixing ratio (g/kg of dry air) is derived using the total and partial pressures of air and water vapor

$$W_i = \frac{622\ e_i}{P_i - e_i}$$

i. SPEED - wind speed (m/sec) is measured directly

j. W DIR - wind direction (magnetic) is measured directly by the sensor package and is relayed to the HP-97

The HP-97 printed outputs were scanned for possible errors and were then affixed to data forms with preprinted legends. Each page, if completely filled, contains 12 complete data frames, 3 rows and 4 columns. Chronological order proceeds from the top left and down each column. The time of data acquisition is given by the first number in each block.

Experiment days are given in Julian days. Experiment runs are either complete ascents or complete descents of the TETHERSONDE system and run numbers are incremented during each day. The BEGIN and END times pertain to the beginning and end times of the complete ascent or descent and not just to the data affixed to each data form. The initial pressure is the surface pressure indicated by a precision aneroid barometer at the beginning of each run. All TETHERSONDE data is presented in Appendix B.

RADIOSONDE DATA

The 403 MHz radiosonde system described in Section 2, proved quite reliable and effected no gaps or blocks of missing data. All radiosonde data was relayed to the ground-based receiver station at the EQR fixed site and was recorded graphically as a multiplexed signal.

Strip chart data was trended and interpreted at the EQR fixed site subsequent to the launch. Data reduction produced pressure, temperature, dewpoint,

humidity, and wet bulb depression at significant levels in the atmosphere. A significant level is needed wherever the vertical rate of change of temperature or humidity changes such that the straight line approximations of temperature and humidity between significant levels is no more different than $\pm$1°C or $\pm$5% RH from the continuous vertical profiles.

All data for all significant levels were vertically plotted on EPA D-31 radiosonde forms. All meteorological data was listed on the same form in DATA BLOCK A. Subsequent quality control ensured the quality and accuracy of the radiosonde data.

The radiosonde data was plotted in a continuous 2 week height-time cross-section. The temperature and humidity fields were analyzed and are presented in Section 8, Data Interpretation. The wind fields are not presented since each experiment is more accurately presented by the high resolution pibal data shown in Appendix A. Radiosonde winds were extremely useful in pre-flight planning.

TELETYPE AND FACSIMILE DATA

A large quantity of meteorological data has been archived that was received through the two teletypes and a map facsimile machine installed at the EQR fixed site for the duration of the experiment. This data was used primarily for pre-flight planning on the range of 6-48 hours.

The teletype data from Circuit "A" consisted mostly of hourly weather observations from airports around the country and from Florida in particular. This was important in pinning the location of moving weather systems that might move through the Tampa area. Hourly surface observations from Tampa airport often proved useful.

Teletype Circuit "C" provided radiosonde data from across the country, including from the Ruskin site near Tampa. It also carried many derived NMC products such as mid and low level trajectory calculations, derived vertical velocities, and expected tropospheric relative humidities.

The most invaluable tool was the map facsimile tied directly to NMC in Washington which produced surface weather maps every 3 hours, radar depictions, upper air maps, satellite imagery, nephanalyses, winds aloft charts, and many

depictions of derived meteorological products such as vorticity and vertical velocities. These charts were received and posted on a daily basis and have been archived chronologically. The facsimile data proved invaluable in helping produce the synoptic summaries.

SECTION 8

METEOROLOGICAL DATA INTERPRETATION

METEOROLOGICAL OVERVIEW

The weather events of the two weeks (Feb 7 - Feb 18) provided a variety of wind and stability regimes with a minimum of precipitation. Figures 13, 14, and 15 present radiosonde data taken at the EQR fixed site in height-time cross-section format and show the vertical temeprature and humidity profiles for the entire twelve days (Feb 7 - 18). Detailed winds fields are given in Appendix B for the nine experimental periods.

The first week was dominated by a mound of Arctic high pressure that settled over the southeast United States producing the climatologically normal northeast wind pattern for the Florida peninsula. Figure 13, showing Feb 7 through Feb 10, indicates little high level temperature change. However, the inversion levels (light shaded areas) and areas of near saturation (vertical lines) change substantially.

The inversion levels are either low-level, produced by surface cooling, or mid-level, produced by subsidence. Low-level inversions are common the first week as morning low temperatures reach into the upper thirties and low forties. The moderating temperature within the air mass are apparent in the rise of the daily temperatures. The freezing level still protrudes below 3000 m (10,000 ft) for this period. Mid-level inversions capping the well mixed layer are common around 1500 m (5000 ft). A frontal wave had moved along the frontal boundary to the south of Florida, causing the activity noticeable on Feb 9. The hatched areas of greater than 80 percent humidity represents cumulus and strato-cumulus buildups that penetrated the troposphere to the base of the inversion. A warm pocket produced by subsidence is noted on Feb 9 and again on Feb 10 which develops into an intense capping inversion (Fig. 14).

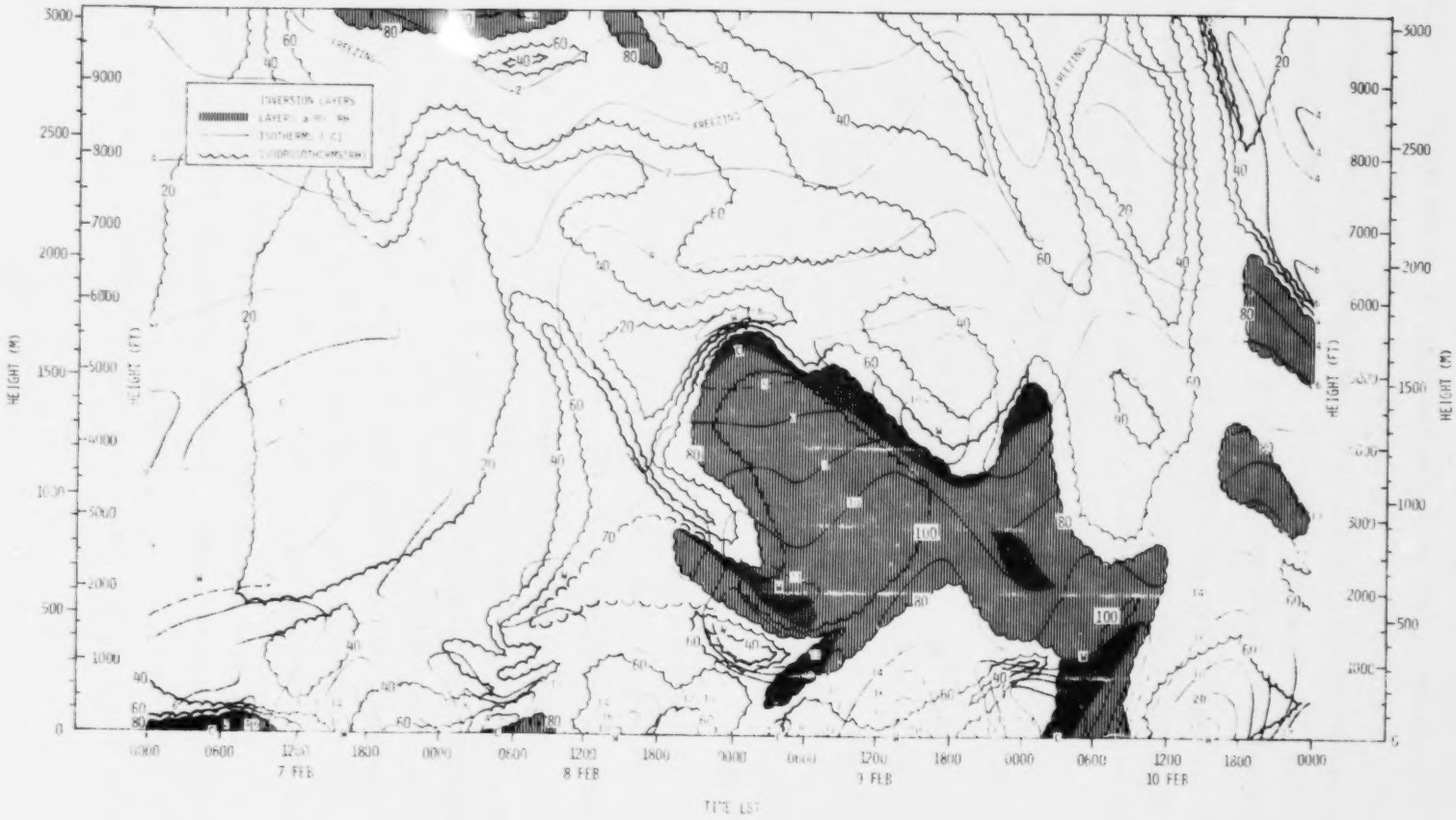

FIGURE 13. Analysis of radiosonde data taken at the EQR fixed site Feb 7 - Feb 10.

By Feb 11 and Feb 12 the low level air mass has been entirely converted to a maritime regime with cumulus convection continually increasing. The diurnal oscillation of the subsidence level is an noteworthy feature as is the marked dryness (RH < 20%) in the subsiding layers. The two days, Feb 11 and Feb 12, are almost identical except that the wind direction has turned from east to southwest by midnight of the 13th.

A frontal passage occurred at Tampa from the west at 1200 LST, Feb 13. A lowering of the middle deck cloud layers proceeded during the morning hours and showers were prevalent. The frontal zone entirely destroyed the capping inversion. Cold air advection was negligible with this front. A southward line of showers formed during the evening of the 13th and moved to the east throuth the area.

Meteorological analysis of the data and the front's origin indicated the air was of Pacific maritime origin cooler and slightly dryer than the previous airmass. Moderate temperatures were the rule on the 14th as cloudiness prevailed. During the 14th the cool front was stalled across southern Florida. A wave moved along on the front late in the day causing light showers.

A shallow ridge of high pressure lay across the Florida peninsula on Feb 14 and 15 producing light winds that were easily affected by the land and sea-breeze regimes (Fig. 15).

A fresh intrusion of cold and dry Arctic air surged through the Southeast moving through Tampa just before midnight on the 15th. A secondary surge 12 hours later pushed the polar outbreak through southern Florida. Dewpoints were driven as low as -10°C (14°F) across central Florida. Middle level cloudiness the morning of the 17th prevented widespread killing frosts. The top of the Arctic air can be seen clearly near 1000 m (3000 ft) at the base of the inversion layer on the 16th and 17th.

A rapid change in the air mass occurs as winds switch to southwesterly on Feb 18. Middle level subsidence becomes pronounced capping the development of low level cumulus. Local frosts again occurred the morning of the 18th. The very shallow inversion produced local inland fogs that burned off quickly.

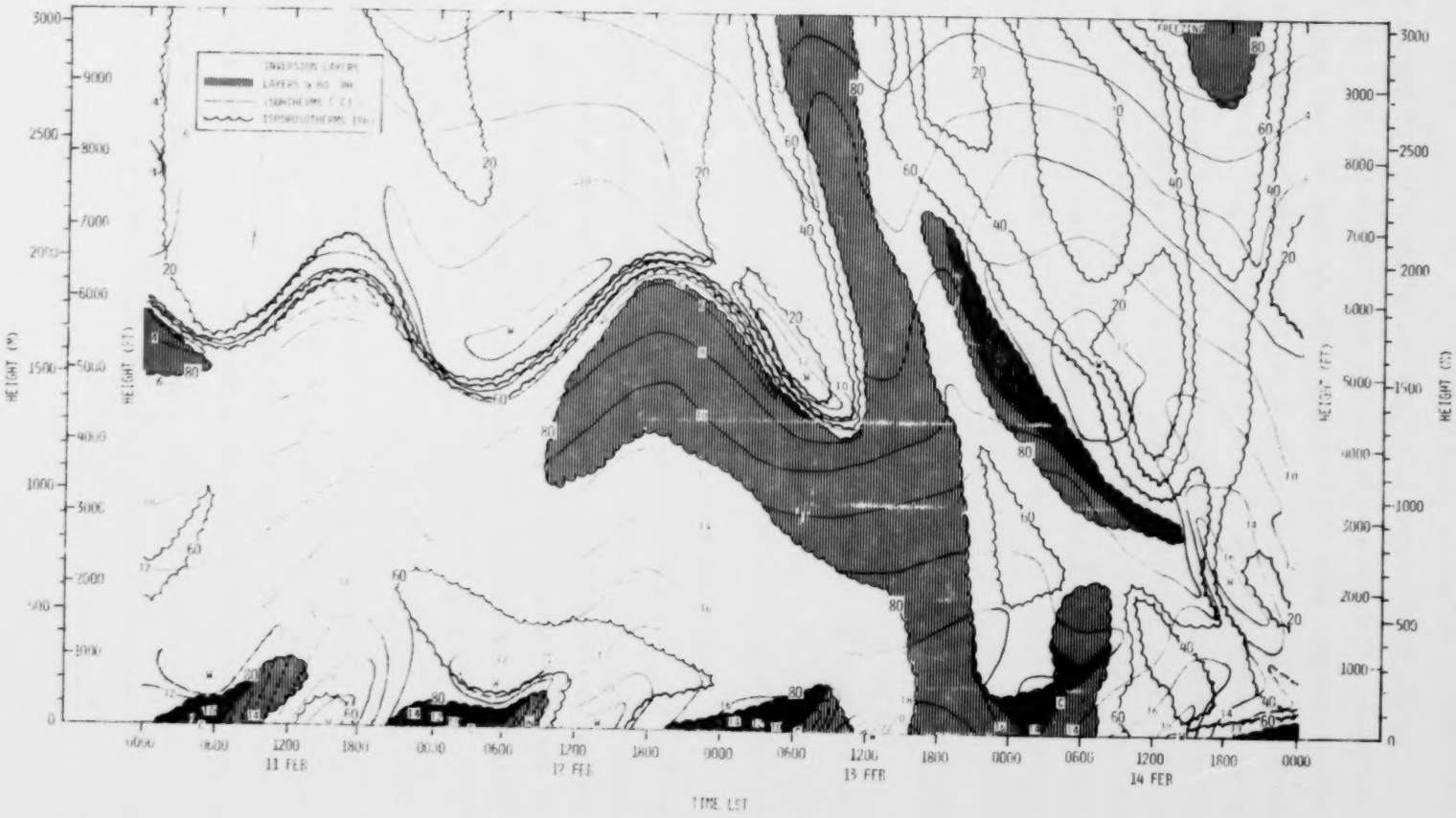

FIGURE 14. Analysis of radiosonde data taken at the EOR fixed site Feb 11 - Feb 14.

THE EXPERIMENTS: METEOROLOGICAL SYNTHESIS

Experiment 1 (Feb 7, 1536-1736 LST)

During this afternoon flight the plume (Fig. 2) headed offshore to the southwest. The two single pibal sites (Tables A-2 and A-3) both indicated a marked vertical wind shear between the surface and 600 meters. Surface northerly winds, a sea breeze effect, were undercutting warmer northeast winds blowing off the Florida peninsula. Figure 13 indicates a thermal inversion between 400 and 600 meters. The surface temperature maximum shown on Feb 7th is at the EQR fixed site and will be much different under the plume over the 14°C (57°F) Gulf. Under these conditions the plume rises only slightly and maintains its identity for great distances (100-200 km). The ambient plume humidities (near 300 meters) ranged from 40-50% at temperatures near 10°C. The plume velocity at this level was about 6-7 m/sec.

Experiment 2 (Feb 8, 1323-1655 LST)

The meteorological conditions for the Feb 8 afternoon flight were similar to those of the first flight. An analysis of the three sets of pibal data (Tables A-3, A-4, and A-5) again indicated a marked wind directional shear up to 700 meters intensified by the low level seabreeze.

The radiosonde data (Fig. 13) again depicts high afternoon temperatures over land. Water temperature remained the same (14°C). The plume (Fig. 3) again headed out to sea and due to the high stability maintained its identity. The centerline would be expected slightly higher than the previous experiment or near 300-400m. Conditions at this altitude during the experiment gave humidities between 60%-70% and temperatures about 12°C. Wind speeds at this level averaged 6-7 m/sec.

Experiment 2A (Feb 10)

This experiment covers all Brookhaven Lab flights during the morning and afternoon of the 10th. One pibal was set up to determine the meteorological conditions. Low level stability again prevailed. Pibal data indicated a strong sea breeze effect and a substantial directional shear.

A significant low level wind speed maximum prevailed into the early morning hours with speeds in excess of 15 meters per second centered at 400

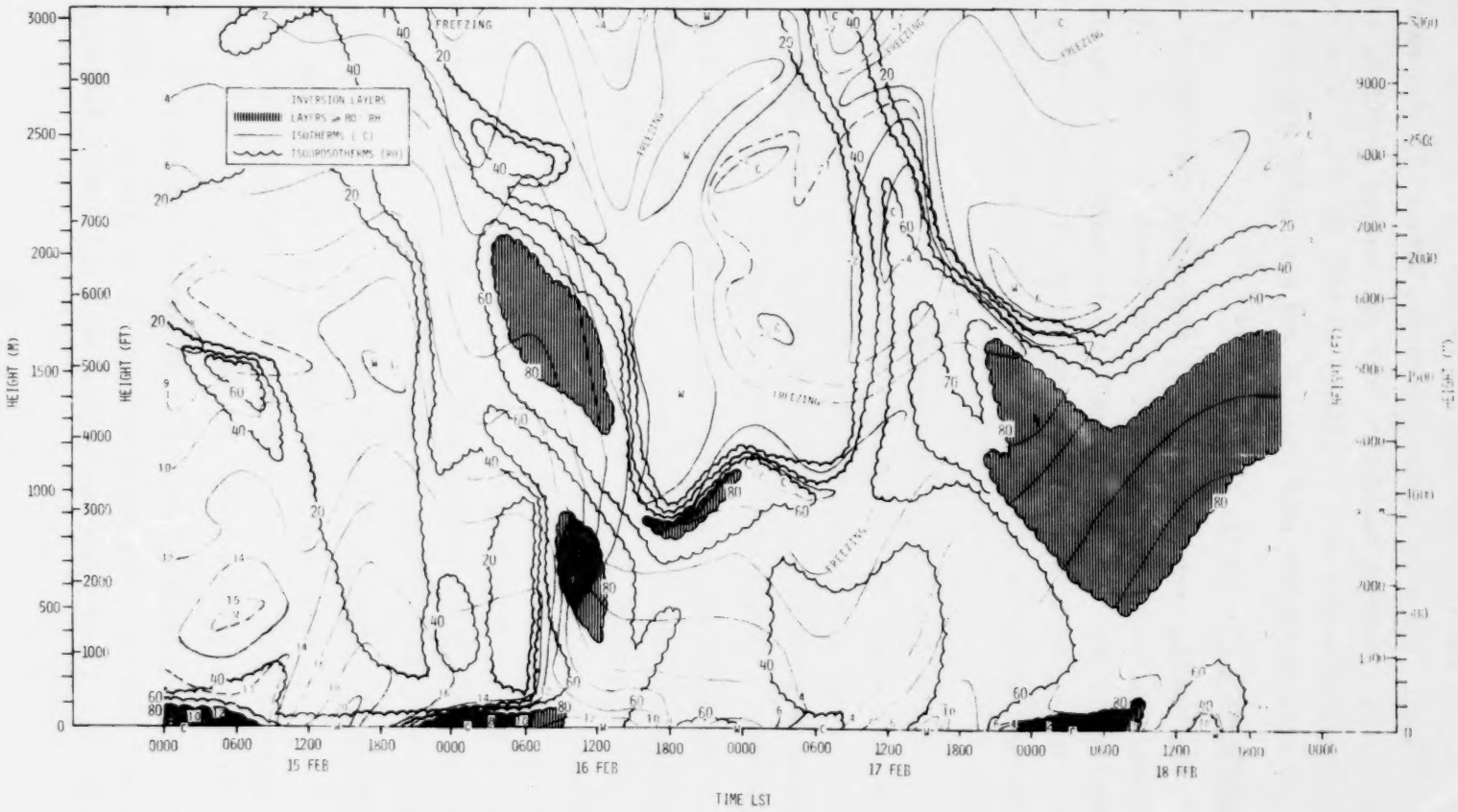

FIGURE 15. Analysis of radiosonde data taken at the EQR fixed site Feb 15 - Feb 18.

meters. As heating progressed the feature lifted to over 1000 meters and dissipated. The plume centerline ranged between 250-450 meters as the day progressed. Morning humidities near 80% lowered to 60% by afternoon and temperatures warmed only slightly from 10°C to 14°C. Wind speeds within the plume were 10-12m/sec near 0800 LST and were still near 8m/sec by afternoon.

Experiment 3 (Feb 10-11, 2330-0235 LST)

During the early evening hours preceeding the night flight a dramatic intensification of the low level jet occurred. The horizontal momentum transfer in the lower 2000 m (6500 ft) increased by at least a factor 2. This feature coincided with the beginnings of a marked mid tropospheric subsidence that can be seen in the radiosonde data analysis on Feb 10, 1800 LST (Fig. 13).

The low level jet reached maximum intensity and depth by 2100 LST on the 10th with speeds of 17 m/sec at 400 m and speeds of 10 m/sec up to 2400 m. Winds veered with height from the surface to beyond 2000 m (6500 ft). Wind speeds of up to 15 m/sec persisted throughout the night in a layer between 300m-400m. Surface winds were only 3-5 m/sec.

The plume was wisked rapidly to the west-southwest staying coherent under the extreme stability conditions (Fig. 5). TETHERSONDE data indicated a slight turning of the wind at 200 meter altitude (from 070°-080°) as the plume crossed the coastline. A strong inversion is indicated at the surface early in the evening of the 10th lasting all night. This feature trapped the plume below 300 m. Meteorological conditions produced humidities of near 50% to 60% at plume level and temperatures of 13°C to 14°C. Wind speed of 12 m/sec were fairly constant at 200 meters (Tables A-6 and A-7).

Experiment 4 (Feb 11, 1615-1928 LST)

By late afternoon of the 11th the sea breeze and the middle level subsidence were still in full force. The surface inversion is forming as the experiment progresses (Fig. 14).

The low level jet begins to reestablish itself as the sea breeze initiates around 2100 LST. Maximum winds were 12 to 14 m/sec at 250 meters (Tables A-8 and A-9). Winds again veered with height, becoming easterly at 800 m.

The plume was caught in the sea breeze and streaked southward along the coast across Clearwater (Fig. 6). Stability conditions increased through the evening. Initially the plume was trapped below 400 m lowering to 300 m by the end of the experiment.

Humidities in the plume ranged from 40% to 60% while temperatures were near 20°C. Wind speeds at 300 meters increased from 6 to 12 m/sec by the experiment's conclusion.

The TETHERSONDE data near the plume's path showed winds as high as 13 m/sec below 100 m.

Experiment 5 (Feb 12, 0713-1435 LST)

Under strong middle tropospheric stabilization, conditions were ideal for long-term plume tracking (Fig. 14). This experiment consisted of two MRI flights which attempted to follow a plume parcel beyond 100 kilometers. Despite the fact that the wind veered constantly with time the plume was coherent as far out as 130 km, the last measurement.

At the plume source, the Anclote Power Plant, a sharp sea-breeze initiated just after 1100 LST. Wind directions switched from 130° to 200° in an hour's time (Table A-10). At the EQR fixed site the wind shift occurred near 1200 LST. During most of the experiment the plume was undergoing a slow translational movement toward the northeast. By the experiment's end the plume appeared to hook to the left moving northward from the plume and then northwestward across the Gulf of Mexico (Fig. 7).

The wind speed associated with the plume motion varied through the day. The early morning low level wind speed maximum was at 300 m peaking to about 16 m/sec during the pre-flight hours. This low level phenomenon dissipated during the morning hours up to the onset of the sea breeze. Plume speeds ranged from 12 m/sec to 5 m/sec during the first flight. The speeds on the second flight, away from the coastline measurements, have been estimated at 8 m/sec.

During the early flight humidities near 80% were experienced. Afternoon values dropped to 60%. TETHERSONDE data indicates a sharp inversion over the water with surface temperatures only 15°C at 1200 LST. Temperatures at plume level vary from 16°C to 20°C as the day progressed.

Experiment 6 (Feb 15, 1427-1709 LST)

As the data in Tables A-13, A-14, and A-15 indicate the wind regime on the afternoon of the 15th was quite turbulent. Wind directions were variable, a sign that unstable convection was occurring. The plume drifted southeastward near the EQR fixed site and toward Tampa Bay (Fig. 8).

All pibal sites measured a speed minimum near 700 meters (2300 ft) throughout the day. This indicates that the plume would undergo substantial mixing throughout the layer below this feature.

TETHERSONDE data indicates a substantial inversion offshore due to the cold water. The inversion is below 200 meters and would not affect the plume at its source even on the coastline.

Radiosonde data inland indicates no low level inversion as surface heating quickly dissipated the near-surface inversion (Fig. 14). The sounding also indicates two inversion levels one at 1500 meters and a lower one at 1000 m.

Drier air accompanied the northwest winds on the 15th. Humidities ranged from 20% to 30%. TETHERSONDE humidity readings offshore are suspect at the end of the experiment after 1650 LST. Continued aspiration probably dried out the wick causing a ficticious wet bulb depression. Temperatures at plume level climbed slowly during the afternoon rising from 15°C to 19°C. Wind speeds were light from 1.5 to 4.0 m/sec.

Experiment 7 (Feb 17, 0750-0926 LST)

Extremely cold Arctic air penetrated the Florida peninsula on Feb 16 and produced wind speeds up to 20 meters per second out of the northwest (Tables A-16, A-17, and A-18). Surface winds during the morning of the 17th swung around to the northeast as a land breeze formed under the surface inversion (Fig. 15). Radiosonde data shows a small inversion level at 500 meters at 1200 LST on the 17th marking the lifting of the morning inversion layer as some limited heating occurred. Surface temperatures were barely able to equal the Gulf water temperature at 14°C (57°F).

The morning MRI flight monitored the plume as it moved southwestward along the coastline (Fig. 10). The plume is caught in an area of significant backing winds with height, a sign of cold advection and negative stability.

Especially during morning hours, plumes caught in a lifting inversion will be violently fumigated for several hours until the inversion dissipates or until the mixing layer becomes deep. However, the heating on the 17th was marginal and fumigation, or downward ventilation, probably occurred for most of the flight.

Temperatures in the plume, assuming an altutude below 300 m, ranged from 3°C-6°C. The air was very dry. The 1200 LST surface dewpoint at Tampa International Airport was -11°C (12°F), approaching an all-time record low. Relative humidities in the plume ranged from 40% to 30%. Wind speeds within the plume at the 200 meter level were erratic beginning near 15 m/sec to about 7 m/sec at the end.

Experiment 8, (Feb 17, 1434-1755 LST)

Wind directions became northwesterly by the afternoon of the 17th. Pibal data shows that winds veered with height in the lower 600 meters (Tables A-19, A-20, and A-21) indicating a reestablishment of stability in the lower levels (Fig. 15). It is likely for the plume to be well defined, especially at the experiment's conclusion, and to remain in the 300-500 m range.

Under these conditions the plume drifted south-southeastward across St. Petersburg (Fig. 11). Wind speeds began to lighten near the surface. The plume movement ranged from 5 to 7 m/sec at the 400 level. Temperatures varied from 5°C to 7°C. Humidities began to rise later in the day as the air began to pick up moisture from the Gulf. Values of 55% to 60% were monitored at plume level.

Experiment 9 (Feb 18, 0718-1046 LST)

Strong warm air advection began to take place aloft during the morning of Feb 18 (Fig. 15). Significant veering with height occurred, especially just above the low level cool land breeze that formed overnight (Tables A-22 and A-23). At the beginning of the experiment the depth of this inversion layer was about 400 meters, gradually weakening as heating progressed.

Under these conditions the plume would be vertically coherent but would undergo substantial lateral shear fanning north and northeast from the Anclote Power Plant (Fig. 12). During the three hours of the experiment wind directions at the plume level, near 400 meters, remained fairly constant.

TETHERSONDE data indicated that during the last hours of the experiment the adiabatic layer near the surface still had not reached plume height and that an inversion still remained at the top of the land breeze. Wind directions from the pibal data (Tables A-22 and A-23) indicates that the land breeze ceases after 1100 LST.

Meteorological monitoring at plume height showed temperatures in the range of 10°C-14°C. Humidities dropped from 80% to 60%. Windspeeds increased during the morning hours from 5 to 10 m/sec.

SECTION 9

UTILITY OF DOUBLE THEODOLITE PIBAL WINDS

The timely collection of accurate wind field data commanded high priority in the planning of EQR's field support of the Tampa Power Plume study. The scope of work was specially modified to deploy an additional pibal crewman to work in conjunction with another to simultaneously track pilot balloon launches. Operational techniques were developed to monitor the balloon's position every 30 seconds and to derive, based on accurate measurements of the observers' positions, the true wind speeds and directions without the need to assume a balloon ascent rate. The results of the double pibal operations were very positive. Several conclusions and recommendations are noted:

Pilot balloon ascent rates do vary from the standard ascent rate. Figures 16 and 17 represent the type of height-time cross-section to which all pibal data were submitted in order to insure vertical and time continuity. The data in Figure 16 were taken by the double pibal crews but the two data sets were treated as single pibal data and averaged. The pibal data analysis in Figure 16 tends to smooth out wind speed and direction irregularities that inexact timing in the azimuth and elevation readings will introduce into the calculations. Height and time continuity are attempted in the analysis yet there is no way of evaluating the accuracy of the "perturbations" in the field, especially above 1000 meters.

Figure 17 represents the same data after consolidation of the two sets of azimuth and elevation angles, the baseline lengths, and its orientation to calculate wind speed and direction (i.e. a double pibal). The greatest difference between the two figures lies near the tops of each one where the wind field at the mid tropospheric inversion is depicted (also see Fig. 14). Oscillations along inversions have been documented in previous studies, so that the purturbations in Fig. 16 could not be rejected out of hand. However, the

analysis presented in Fig. 17 is unquestionably more accurate and agrees with the inversion heights given from the radiosonde analyses of 0600 LST and 1200 LST.

Inaccurate height data substantially affect calculated wind speeds and directions. The difference between the two figures is not just that plots of pibal data have been adjusted up and down, but that the windspeed and directions themselves have been corrected. The improved accuracy of the double pibal technique is evidenced in the regularity of the analyses of Fig. 17. The synoptic situation was one of extreme stability in which smoother patterns are to be expected.

Double pibal results are critically dependant on precise and simultanous measurements of azimuth and elevation. Analytically the solution of two sets of angles together with a baseline and its orientation is simple trigonometry. However, the application of the program, inputed into an HP-97 printing calculator, gave results that, at times, were quite erratic in their vertical continuity.

A detailed analysis of the calculations show that two of the highly critical inputs are the $(\theta_{t+1} - \theta_t)$ (azimuth) and $(\phi_{t+1} - \phi_t)$ (elevation) between each observation for each site. These differences must be accurate to $\pm 0.1°$ in order that derived wind speeds will be accurate to ± 0.4 m/sec and that directions will be accurate to 3°.

When the azimuth and elevation angles are steady with time during an ascent a high degree of accuracy can be maintained. Unfortunately, by definition, one observer must watch the balloon from afar since the balloon launch is done at one theodolite. Many balloons are lost by this observer due to rapid angular changes, especially if the wind is bringing the balloon toward this observer.

The other critical angle is $\theta_{1,t} - \theta_{2,t}$ (azimuth). When each observer is looking at the balloon at the same azimuth angle the solution blows up. In all instances when the balloon curved downwind and crossed an extension of the observer baseline ($|\theta_{1,t} - \theta_{2,t}| < 5°$), the wind speed and direction calculations become obviously unstable. In attempting to rectify this problem, it was found that the angles had to be expressed with $\pm 0.01°$ accuracy before

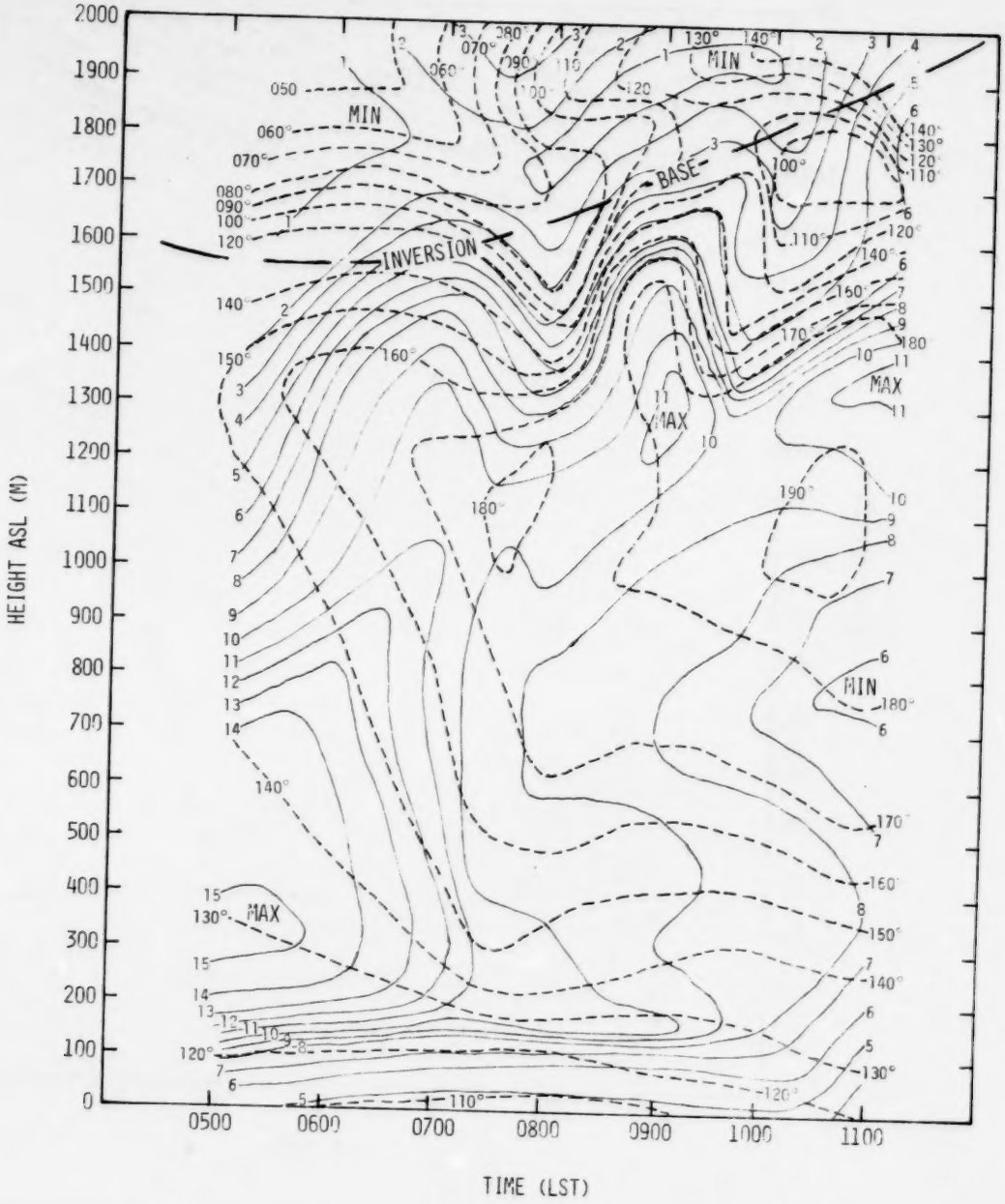

FIGURE 16. Height-time cross-section analyses of wind speed and direction for experiment 5 at Anclote Island produced by averaging the two single pibal results using a standard ascent rate.

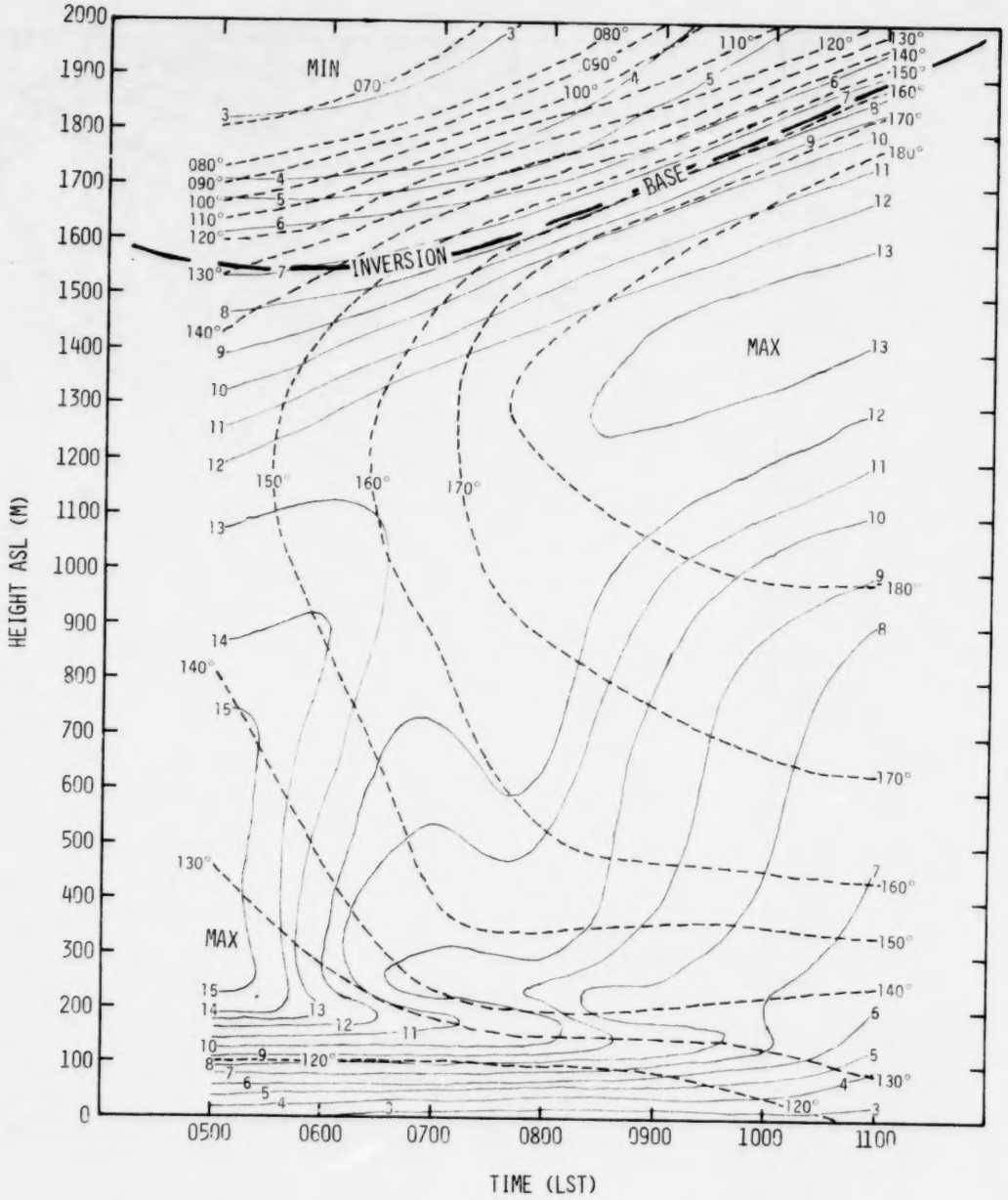

FIGURE 17. Height-time cross-section analyses of wind speed and direction for experiment 5 at Anclote Island produced by using two sets of azimuth and elevation angles simultaneously and computing balloon heights.

the solutions would have proper continuity.

Coincident timing of observations is critical to ±1 sec under many conditions. It is not difficult to analyze those double pibal observations in which the balloon arcs across the baseline downwind and to compute the exact time according to each observer that the azimuth angles are equal to the baseline orientation. This was done in twelve cases and the average angular disparity was 4.3° assuming that one observer was incorrectly aligned and that observations were made simultaneously.

It is known that errors of 4.3° in orientation will not occur since pre- and post- orientation checks were required of each observer. It was then known that the timing, either from human or mechanical reasons, was the culprit and that angular readings were not simultaneous.

A system must be set up so that each pibal observer simultaneously hears the signal to record an observation. The communication system that was used by the EQR double pibal crew on Anclote Island and then at Howard Park - Sunset Beach was a battery operated walkie-talkie. Only intermittant conversations could be made or else the batteries would become depleted. These instruments were mobile and could be activated by the pibal observer releasing the balloon so that dual tracking could be initiated. It was at this time that the standard 30-second beepers were activated and no further communication between observers was conducted.

The beepers were soon discarded when it was found that they varied from 28 to 32 seconds, especially when their battery voltage dropped. Also it was suspected that beeps were missed altogether or that short erroneous beeps were periodically inserted. A number of pibal runs from the Anclote Island set showed evidences of 20-30 seconds out of sync at the end of 12 minutes.

The best method available turned out to be the use of wrist watches, since stop watches were not provided. The release and radio call were made at an even minute mark and it was up to the other observer to synchronize the release to his watch. Errors of up to ±5 seconds can occur just at release. It is also a difficult task to watch the theodolite scope and a wristwatch simultaneously, resulting in missed and late readings.

It is possible to calculate smooth balloon heights using the double pibal technique and to use it to calculate accurate pibal data. In a test of the accuracy of the standard ascent rate principle, each double pibal was inputed through the HP-97 program. The program produced 30-sec balloon heights which were compared to the standard ascent rates and to all other releases for that day. It was found that, even when height values were meaningless where the two observer azimuth angles were $< 5°$ apart, the heights looked reasonable both below and above this point. Smooth curves were analyzed through the height data for each release to determine the best fit ascent rate.

The height at 30-second intervals was interpolated from each curve and was inputed into the double pibal data. Figure 17 was calculated in this manner. The height after 12.0 minutes is 1600 meters according to the standards for 10 gram pibal releases. Forty-nine double pibal releases were used, eighteen on the Anclote Keys and twenty-one on the coast, to determine a 12-minute height of 1662 meters for 10 gram pibal releases representative of the 2 weeks of experiments in Florida.

Precise baseline and orientation measurements are required to produce accurate double pibal data. For the two double pibal set-ups baselines of 629 and 1776 meters were used. These values were calculated from precision azimuth readings taken from each site of notable features that could be accurately marked on USGS maps. Each observer first oriented his theodolite toward the other so that they were exactly 180° out of phase and at the same elevation.

The largest island of the Anclote Keys offered few landmarks except that of a lighthouse at its southernmost end. However, only one observer was able to sight on it due to height of the vegetation. The Anclote Plant and nearby a radio tower were used to sight on as well as a lighted buoy to the south of the island. All angles were recorded to $\pm 0.1°$.

Unfortunately, after initial double pibal height calculations were compared to those of Howard Park-Sunset Beach, the Anclote heights were 10% higher systematically. This fact indicated that the computed Anclote baseline distance was probably 10% too large. Additional computations showed that the three sets of orientation points did not give consistent baseline

results and that one in particular, the one originally used, was probably 10% too large.

The problem was reduced to two aspects: first, the orientation of the two sites to the buoy were within 2° of each other, providing very little significant accuracy. Secondly, measurements of orientation angles should be to ±0.01° at all times. The calculated baseline measurement 629 meters is probably accurate to ±4%.

The orientation at Howard Park-Sunset Beach was accomplished to ±0.01° accuracy using two orientation points. The lighthouse and the Anclote Power Plant stack were easily seen to both observers. The baseline distance of 1776 meters is approaching the limit of practicality for viewing and produces about the best accuracy one can expect. The baseline is accurate to ±1% which would produce only inconsequential errors in the wind speed and direction results.

On the basis of the preceding experiences, the following recommendations are summarized:

1. Ground-to-ground FM radio communication between double pibal sites should be set up to simultaneously carry a pre-taped countdown for the balloon launch and for each 30-second reading.
2. All double pibal observations of azimuth and elevation should be interpolated to ±0.01° accuracy.
3. All double pibal releases must be made by the downwind observer, accounting for low level wind shears that will swing the balloon around.
4. Double pibal sites should each be oriented utilizing at least three points, two of which preferably located perpendicular to the line of double theodolite orientation, whose azimuthal line of sight should be measured within ±0.01°.
5. Theodolite systems should eventually be converted to digital output systems that automatically record the balloon azimuth and elevations at whatever frequency is needed. The observer initializes the system and maintains the balloon under the theodolite cross-hairs for the entirety of the flight.

APPENDIX A
PIBAL WINDS FOR ANCLOTE KEYS PLUME STUDY (7-18 FEB 77)

Derived wind data (height, direction, and speed) and raw observations (zenith, azimuth, and time of ascent) are available in tabular form from the Environmental Quality Research, Inc. for the cost of copying and handling charges.

APPENDIX B
TETHERSONDE DATA FOR ANCLOTE KEYS PLUME STUDY (10-18 FEB 77)

Vertical profile data (time, pressure, temperature, height, potential temperature, relative humidity, dew point, mixing ratio, wind speed, and wind direction) are available in tabular form from the Environmental Quality Research, Inc. for the cost of copy and handling charges.